CHEMICAL ESSAYS.

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ESSAY

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ESSAY I.

OF THE COMPOSITION AND ANALYSIS OF GUNPOWDER.

GUNPOWDER is an artificial composition, consisting of *salt-petre*, *sulphur*, and *charcoal*. The principal things to be respected in the making of gunpowder are,—the goodness of the ingredients;—the manner of mixing them;—the proportion in which they are to be combined;—and the drying of the powder after it is made.

Saltpetre, in its crude ſtate, whether it be brought from the Eaſt Indies, or made in Europe, is generally, if not univerſally, mixed with a greater or leſs portion of common ſalt: now a ſmall portion of common ſalt injures the goodneſs of a large quantity of gunpowder; hence it becomes neceſſary, in making gunpowder, to uſe the very fineſt ſaltpetre.—The pureſt ſulphur, is that which is ſold in the ſhops under the name of flowers of ſulphur; but the roll ſulphur, being much cheaper than the flowers of ſulphur, and being alſo of a great degree of purity, it is the only ſort which is uſed in the manufacturing of gunpowder.—With relation to the charcoal, it has been generally believed that the coal from ſoft and light woods was better adapted to

the making of gunpowder, than that from the hard and heavy ones; thus *Evelyn* ſays of the hazel, that "it made one of the beſt coals uſed for gunpowder, being very fine and light, till they found alder to be more fit*." And in another place he thinks that lime-tree coal is ſtill better than that from alder†. An eminent French chemiſt has ſhewn, from actual experiment, that this opinion in favour of coal from light woods is ill founded; he affirms, that powder made from lime-tree coal, or even from the coal of the pith of elder tree, is in no reſpect preferable to that made from the coal of the hardeſt woods, ſuch as guaiacum and oak.

* Evelyn's Silva, by Dr. Hunter, p. 223.

† Id. p. 946.

oak*. This remark, if it be confirmed by future experience, may be of uſe to the makers of gunpowder; as it is not always an eaſy matter for them to procure a ſufficient quantity of the coal of ſoft wood.

The mixture of the materials of which gunpowder is made, ſhould be as intimate and as uniform as poſſible; for, in whatever manner the exploſion may be accounted for, it is certain that the three ingredients are neceſſary to produce it. Saltpetre and ſulphur mixed together give no exploſion; ſulphur and charcoal give no exploſion; and though ſaltpetre and charcoal, when intimately mixed, do give an exploſion, yet it is, probably, of far leſs force than what is produced from a mixture

* Chym. par M. Baumé, Vol. I. p. 455.

ture of the three ingredients. I have said, *probably*; because this point does not seem to be quite settled at present, as may appear from the following opinions, of two eminent chemists, each of whom appeals to experience.—" Un mêlange de six onces de nitre et d'une once de charbon produit une poudre qui a *moitié moins* de force que toutes celles dans lesquelles on fait entrer du soufre : cette substance est donc absolument essentielle à la composition de la poudre. Dans le temps que je travaillois sur cette matiere, quelques particuliers proposerent de faire de la poudre sans soufre : ils promettoient qu'elle seroit plus forte, —La poudre dans laquelle on fait entrer une petite quantité de soufre,

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augmente de force *du double**."—
"The principal ingredients of gunpowder, and those to which it owes its force, are nitre and charcoal; for these two ingredients well mixed together, constitute gunpowder at least *equal*, if not *superior in strength* to common gunpowder (as I found by experience), and may be seen in the Memoire of Count Saluce inserted in the *Melanges de Philosophie et de Mathematiques, de l'Academie Royale de Turin*. The sulphur seems to serve only for the purpose of setting fire to the mass with a less degree of heat†."—If I may trust some crude experiments which I have made with a com-

* Chy. par. M. Baumè, Vol. I. p. 461.

† Philos. Transf. 1779, p. 397, where the reader will find several ingenious experiments relative to the nature of gunpowder by Dr. Ingenhousz.

a common powder Trier, I muſt accede to the opinion of M. Baumé; as I repeatedly found that equal *bulks* of common powder, and of the ſame ſort of powder, freed from its ſulphur by a gentle evaporation, differed very much both in the loudneſs and force of the exploſion; the powder which had loſt its ſulphur being inferior to the other in both particulars. It is not without reaſon, that equal *bulks* are here ſpecified, for any definite meaſure of common powder weighs more than the ſame meaſure of powder which has loſt its ſulphur; hence the reſult of experiments made with equal *weights* of theſe powders, will be different from that which is derived from the exploſion of equal *bulks*: may not this obſervation tend to reconcile the

opinions before mentioned? But whether sulphur be an absolutely necessary ingredient in the composition of gunpowder or not, it is certain that an accurate mixture of the ingredients is essentially requisite. In order to accomplish this accurate mixture, the ingredients are previously reduced into coarse powders, and afterwards ground and pounded together, till the powder becomes exceeding fine; and when that is done the gunpowder is made. But as gunpowder, in the state of an impalpable dust, would be inconvenient in its use, it has been customary to reduce it into grains, by forcing it, when moistened with water, through sieves of various sizes.

The necessity of a complete mixture of the materials, in order to

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have good gunpowder, is ſenſibly felt, in the uſe of ſuch as has been dried after having been accidentally wetted. There may be the ſame weight of the powder after it has been dried, that there was before it was wetted; but its ſtrength is greatly diminiſhed on account of the mixture of the ingredients being leſs perfect. This diminution of ſtrength proceeds from the water having diſſolved a portion of the ſaltpetre (the other two ingredients not being ſoluble in water); for upon drying the powder, the diſſolved ſaltpetre will be cryſtallized in particles much larger than thoſe were, which entered into the compoſition of the gunpowder, and thus the mixture will be leſs intimate and uniform, than it was before the wetting. This wetting

ting of gunpowder is often occasioned by the mere moisture of the atmosphere. Great complaints were made concerning the badness of the gunpowder used by the English in their engagement with the French fleet off Grenada, in July, 1779; the French having done much damage to the masts and rigging of the English, when the English shot would not *reach* them. When this matter was inquired into by the House of Commons, it appeared that the powder had been injured by the moisture of the atmosphere; it had concreted into large lumps, in the middle of which the saltpetre was visible to the naked eye. If the wetting has been considerable, the powder is rendered wholly unfit for use; but if no foreign substance has been mixed with

it except fresh water, it may be made into good gunpowder again, by being properly pounded and granulated. If the wetting has been occasioned by salt water, and that to any considerable degree, the sea salt, upon drying the powder, will remain mixed with it, and may so far vitiate its quality, that it can never be used again in the form of gunpowder. However, as, by solution in water and subsequent crystallization, the most valuable part of the gunpowder, namely, the saltpetre, may be extracted, and in its original purity, even from powder that has been wetted by sea water, or otherwise spoiled, the saving a damaged powder, is a matter of national œconomy, and deservedly attended to in the Elaboratory at Woolwich.

The

The proportions in which the ingredients of gunpowder are combined together, are not the same in different nations, nor in different works of the same nation, even for powder destined to the same use. It is difficult to obtain from the makers of gunpowder, any information upon this subject; their backwardness in this particular, arises not so much from any of them fancying themselves possessed of the best possible proportion, as from an affectation of mystery, common to most manufacturers, and an apprehension of discovering to the world, that they do not use so much saltpetre as they ought to do, or as their competitors in trade really do use. Saltpetre is not only a much dearer commodity than either sulphur or charcoal, but

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it enters alſo in a much greater proportion into the compoſition of gunpowder, than both theſe materials taken together; hence, there is a great temptation to leſſen the quantity of the ſaltpetre, and to augment that of the other ingredients; and the fraud is not eaſily detected, ſince gunpowder, which will explode readily and loudly, may be made with very different quantities of ſaltpetre.

Baptiſta Porta died in the year 1515; he gives three different proportions for the making of gunpowder, according as it was required to be of different ſtrength*. I have reduced his proportions, ſo that the reader may ſee the quantities of the ſeveral ingredients, contained in 100 pounds

* Mag. Nat. L. XII. c. 3.

pounds weight of each ſort of powder.

	Weak.	Strong.	Strongeſt.
Saltpetre	$66\frac{2}{3}$ lb.		80
Sulphur	$16\frac{2}{3}$	$12\frac{1}{2}$	10
Charcoal	$16\frac{2}{3}$	$12\frac{1}{2}$	10
	100	100	100

It is ſomewhat remarkable, that, in all theſe proportions, the ſulphur and charcoal are uſed in equal quantities. *Cardan* died about ſixty years after Baptiſta Porta, and in that interval, the proportions of the ingredients of gunpowder ſeem to have undergone a great change. Cardan's proportions for great, middle-ſized, and ſmall guns, are expreſſed in the following table.*

Salt-

* Card. Oper. Vol. III. p. 379.

	Gt. Guns.	Mid. fized.	Small.
•Saltpetre •	50lb.	$66\frac{2}{3}$	$83\frac{1}{3}$
Sulphur	$16\frac{2}{3}$	$13\frac{1}{3}$	$8\frac{1}{3}$
Charcoal	$33\frac{1}{3}$	20	$8\frac{1}{3}$
	100	100	100

For great and middle-fized guns, we fee a much greater proportion of charcoal than of fulphur, was ufed in Cardan's time ; at prefent, I believe, it is in moft places the reverfe, or at leaft, the charcoal no where exceeds the fulphur. I have put down the proportions ufed at prefent in England, France, Sweden, Poland, and Italy, for the beft kind of gunpowder.

	Eng.	Fran.	Swed.	Pol.	Italy.
Saltpetre	75	75	75	80	76½
Sulphur	15	9½	16	12	12½
Charcoal	10	15½	9	8	12½
	100*	100‖	100‡	100‡	101½†

Several experiments have been lately made in France, in order to determine the exact proportions of the several ingredients which would produce the strongest possible powder; these proportions when reduced, as all the rest have been, to the quantity

* These are said to be the proportions of government powder.—Pemb. Chem. p. 207.

‖ Chem. Dict. & Baumé's Chem. Vol. I. p. 466.

‡ Mem. de Chem. Vol. II. p. 425, where it is said, that two specimens of powder from Holland gave only 71lb. of saltpetre from 100 of powder.

† Comm. Scien. Bonon. Vol. IV. p. 113.

tity compofing one hundred pounds of gunpowder, are

Saltpetre	80 lb.
Charcoal	15
Sulphur	5
	100

From hence it would appear, that in a certain weight of faltpetre, the powder would produce the greateft effect, when the weight of the charcoal was to that of the fulphur, as 3 to 1. On the other hand, experiments are produced from which it is to be concluded, that in a certain weight of faltpetre the beft powder is made, when the fulphur is to the charcoal, in the proportion of 2 to 1. From thefe different accounts, it feems as if the problem of deter-

mining the very beſt poſſible proportion was not yet ſolved.

In drying gun-powder, after it is reduced into grains, there are two things to be avoided, too much and too little heat. If the heat is too great, a portion of the ſulphur will be driven off, and thus the proportion of the ingredients being changed, the goodneſs of the powder, ſo far as it depends on that proportion, will be injured. In order to ſee what quantity of ſulphur might be ſeparated from gun-powder, by a degree of heat not ſufficient to explode it, I took 24 grains of the powder marked F F in the ſhops, and placing it on a piece of poliſhed copper, I heated the copper by holding it over the flame of a candle; the gun-powder ſoon ſent forth a ſtrong ſulphureous

vapour;

vapour; and when it had been dried so long that no more fume or ſmell could be diſtinguiſhed, the remainder weighed 19 grains, the loſs amounting to 5 grains. The remainder did not explode by a ſpark like gunpowder, but like a mixture of ſaltpetre and charcoal, and it really was nothing elſe, all the ſulphur having been diſſipated. Gunpowder was formerly dried by being expoſed to the heat of the ſun, and this method is ſtill in uſe in France, and in ſome other countries; afterwards a way was invented of expoſing it to a heat equal to that of boiling water; at preſent it is moſt generally in England dried in ſtoves heated by great iron pots; with any tolerable caution no danger of exploſion need be apprehended from this method. All

the watery parts of the gunpowder may be evaporated by a degree of heat greatly leſs than that in which gunpowder explodes, that degree having been aſcertained by ſome late experiments, to be about the 600th degree on Fahrenheit's ſcale, in which the heat of boiling water is fixed at 212. There is more danger of evaporating a portion of the ſulphur, in this way of drying gunpowder, than when it is dried by expoſure to the ſun.

The neceſſity of freeing gunpowder from all its moiſture, is obvious from the following experiment, which was made ſome years ago before the Royal Society. A quantity of gunpowder was taken out of a barrel, and dried with a heat equal to that in which water boils; a piece of ord-

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nance was charged with a certain weight of this dried powder, and the diſtance to which it threw a ball was marked. The ſame piece was charged with an equal weight of the ſame kind of powder, taken out of the ſame barrel, but not dried, and it threw an equal ball only to one half the diſtance. This effect of moiſture is ſo ſenſible, that ſome officers have affirmed, that they have ſeen barrels of gunpowder which was good in the morning, but which became (by attracting, probably, the humidity of the air) good for nothing in the evening*. In order to keep the powder dry, by preventing the acceſs of the air,

* — qu' il avoit vu, dans les guerres d' Italie, quelques barrels de poudre qui étoit bonne le matin, et qui ne valoit rien le ſoir. Hiſt. Nat. de l'Eſpagne, p. 82.

air, it has been propoſed to line the barrels with tin foil, or with thin ſheets of lead, after the manner in which tea-boxes are lined*.—Would it not be poſſible to preſerve powder free from moiſture, and from the loſs of a part of its ſulphur in hot climates, by keeping it in glazed earthen bottles, or in bottles made of copper or tin, well corked?

This diſpoſition to attract the humidity of the air, is different in different ſorts of powder, it is the leaſt in that which is made from the pureſt ſaltpetre; pure ſaltpetre, which has been dried as gunpowder is dried, does not become heavier by expoſure to the atmoſphere; at leaſt, its increaſe of weight is very ſmall, not amounting, as far as my experiments have

* Hiſt. Nat. de l'Eſpag.

have informed me, to above one 72d part of its weight; I rather think that it does not acquire any increaſe of weight. But ſaltpetre mixed with ſea ſalt, attracts the humidity very ſenſibly, and hence, though there ſhould be the ſame weight of ſaline matter in a certain weight of gun-powder, yet the goodneſs of the powder may be very variable not only from the foreign ſaline matter, be it ſea ſalt, or any other ſalt, injuring the quality of the powder as being an improper ingredient, but from its rendering the powder more liable to become humid.

Saltpetre being the ingredient, in which there is the greateſt room for fraud, in the compoſition of gun-powder, and on the quantity of which its ſtrength chiefly depends, the rea-

der will excuſe the minuteneſs of the following proceſs, to aſcertain the quantity of ſaltpetre contained in any ſpecimen of gunpowder.

Take any quantity of gunpowder, pound it in a glaſs mortar till all the grains are broken, lay it before a gentle fire till it be quite dry, in that ſtate weigh accurately any quantity of it, ſuppoſe 4 ounces; boil theſe four ounces in about a quart of water, the boiling need neither be violent nor long continued, for the water will readily diſſolve all the ſaltpetre, or other ſaline matter, and not a particle of either the ſulphur or the charcoal of the powder. In order to ſeparate the water containing the ſaltpetre, from the ſulphur and charcoal, pour the whole into a filter made of brown paper; the water

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containing the ſaltpetre will run through the paper, and muſt be carefully preſerved; the charcoal and ſulphur will remain upon the paper. But as ſome particles of ſaltpetre will ſtick both to the filtering paper and to the maſs of ſulphur and charcoal, theſe are to be repeatedly waſhed, by pouring hot water upon them, till the water in running through the filter is quite inſipid; then we may be certain, that we have all the ſaltpetre originally contained in the powder, now diſſolved in the water, and all the ſulphur and charcoal remaining a mixed maſs upon the filter. Theſe reſpective quantities may be aſcertained without much difficulty. The water containing the diſſolved ſaltpetre, muſt be evaporated by a gentle heat; the ſaltpetre cannot be

evaporated by the ſame degree of heat which evaporates the water, all the ſaltpetre then contained in the gunpowder, will remain after the water is diſperſed, and being carefully collected and weighed, it will ſhew the quantity of ſaline matter contained in the powder. Dry the maſs of ſulphur and charcoal, by laying the filtering paper containing it before the fire; it ſhould be made as dry as the powder was before it was diſſolved in the water: in that ſtate weigh the ſaltpetre and charcoal; and, when the experiment has been accurately made, the weight of the ſaltpetre, added to that of the mixture of ſulphur and charcoal, will juſt amount to four ounces, the weight of the powder. The quantity of ſaline matter contained in any ſpecimen of

gun-

gunpowder, being thus aſcertained, its quality may be known by diſſolving it in water, and cryſtallizing it; if any part of it cryſtallizes in little cubes, it is a ſign that it contains ſea ſalt; or if any part of it, after being duly evaporated, will not cryſtallize, it is a ſign that it contains another ſort of impurity, called by ſaltpetre makers, the *mother of nitre*, which powerfully attracts the humidity of the air.

The gunpowder marked F F, was analyſed in the following manner. Twenty-four grains, by evaporating the ſulphur, were reduced to nineteen; theſe nineteen grains gave, by ſolution in water and ſubſequent filtration and cryſtallization, ſixteen grains of ſaltpetre, the charcoal, when properly dried, weighed three grains.

Ac-

According to theſe proportions, 100 pounds of this kind of gunpowder conſiſted of

Saltpetre	$66\frac{2}{3}$
Sulphur	$20\frac{5}{6}$
Charcoal	$12\frac{1}{2}$
	100 lb.

I tried this gunpowder in two or three other ways by taking larger quantities of it, but the quantity of ſaltpetre was always 66 lb. together with ſome fractional part of a pound, from 100 lb. of gunpowder. The powders marked with a ſingle and a double F, differ in the ſize of the grain, but they do not ſeem to differ, as far as I have tried them, in the quantity of the ſaltpetre they contain. From ſome ſorts of powder, I have got after the rate of 76 lb. of ſaltpetre, from 100 lb. of the gunpowder.

The method of analyſing gunpowder, by evaporating the ſulphur, is not wholly to be relied upon; I have often obſerved, that when mixtures of ſulphur and charcoal have been expoſed to evaporation, on a plate of heated copper, the remainder has weighed leſs than the charcoal which entered the compoſition, part of it having been carried off by the violent evaporation of the ſulphur: and hence the proportion of ſulphur in the above analyſis is probably too great. I am aware that this obſervation is wholly oppoſite to the concluſion of M. Baumé, who contends, that one twenty-fourth part of the weight of the ſulphur employed in any mixture of ſulphur and charcoal, adheres ſo ſtrongly to the charcoal, that it cannot be ſeparated from

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it without burning the charcoal.— I can only ſay, that he ſeparated the ſulphur by burning it, and I ſeparated mine by ſubliming it without ſuffering it to take fire, and this difference in the manner of making the experiment, may perhaps be ſufficient to account for the different reſults.—But it is unneceſſary to purſue this ſubject further; there are ſeveral things to be attended to in forming a complete analyſis of gunpowder, which any perſon tolerably well verſed in chemiſtry, would certainly take notice of, if the analyſis of any particular powder was required to be made, and which cannot in this general view be minutely deſcribed: and, indeed, it is the leſs neceſſary to enter into a detail on this ſubject; as the ſtrength of the

powder

powder is not much affected by small variations in the quantities of the sulphur and charcoal, which enter into its composition; and the method of ascertaining the quantity and quality of the saltpetre, in any particular gunpowder, has been sufficiently explained.

In order to judge with more certainty concerning the effect of sea salt, when mixed with saltpetre in attracting the humidity of the air, I made the following experiment. Five parts of pure saltpetre in powder, were exposed for a month to a moist atmosphere, but I did not observe that the saltpetre had gained the least increase of weight; for the same length of time, and in the same place, I exposed four parts of saltpetre

mixed

mixed with one of common ſalt, and this mixture had attracted ſo much moiſture, that it was in a ſtate of fluidity.

ESSAY II.

OF COMMON SALT.

COMMON salt is a neutral salt; it has neither an acid nor an alkaline taste, nor does it change the blue colour of vegetables into a red as acids do, nor into a green as alkalies do. It consists of two things, of an *acid* peculiar to itself, and of the alkali which is separable from the ashes of marsh samphire and other maritime plants, and which

has been denominated the *mineral* or *fossile fixed alkali.* The fossile alkali, as was observed of the vegetable alkali, when the manner of decomposing saltpetre was explained, is more powerfully attracted by the acid of vitriol than by the acid of common salt; hence common salt is effectually decomposed when it is distilled in conjunction with the acid of vitriol, for this acid expels the acid of common salt from its union with the mineral alkali, and unites itself with it in its stead: the acid of common salt being thus disengaged from its basis, is easily, by the heat, raised in vapour, and forced into the receiver. The acid of common salt, thus obtained, is very volatile, constantly emitting white fumes; and it is usually called the *marine acid,*

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the *muriatic acid, Glauber's fuming acid* or *ſpirit of ſalt*. If the reader pours a few drops of very ſtrong acid of vitriol on a ſmall portion of dry common ſalt, he will ſee a white vapour ariſing from the ſalt; this vapour is the moſt volatile part of the acid of the ſalt, and a judgment may be formed of its pungency and volatility, from its preſently infecting the air with its ſmell to a great extent. This acid vapour is a kind of air, for it retains its elaſticity for ſome time, not being readily condenſable by cold. It has engaged the attention of Dr. Prieſtley; and, with his accuſtomed ingenuity, he has made ſeveral experiments, from which we learn, that this vapour, when condenſed, conſtitutes an acid which is twice as heavy as rain water, and the

the ſtrongeſt acid of ſalt may be conſidered as conſiſting of one third of this elaſtic vapour, and of two thirds of water*. After the extraction of the *acid*, which is one of the conſtituent parts of common ſalt, there remains, in the veſſel uſed for the diſtillation, a compound maſs, conſiſting of the *acid of vitriol* united with the *mineral fixed alkali*, the other conſtituent part of common ſalt: this is proved by diſſolving the maſs, and cryſtallizing it, for the cryſtals are preciſely the ſame as would reſult from a direct combination of the acid of vitriol with the mineral fixed alkali. The ſalt reſulting from a decompoſition of common ſalt by means of the acid of vitriol, or from a direct combination of that acid with

* Philoſ. Tranſ. 1772, p. 239.

with the mineral alkali, is the *genuine Glauber's falt*. The artificial compofition of common falt, confirms the account we have given of its conftituent parts from its analyfis, for if we combine the acid procured from diftilling common falt and acid of vitriol together, with the mineral fixed alkali, there will refult from their union, a falt, in all refpects the fame as common falt, except that it will be fomewhat more pure than common falt; the falt thus produced is called *regenerated falt*.

Common falt is generally diftinguifhed by mineralogical writers into three different forts—*foffile falt*—*fpring falt*—*fea falt*. In chemiftry though we admit this divifion, as ferviceable in pointing out the three general fources from which common

 falt

ſalt is moſt copiouſly derived, yet we reckon all theſe ſalts, when pure, to be of the ſame ſort; they are all compoſed of the *marine acid*, and of the *mineral fixed alkali*.

Foſſile or *rock ſalt*, is found in large beds in the bowels of the earth, in every quarter of the globe; it is ſometimes cryſtallized, and as tranſparent as a diamond, and it has thence been called *ſal gemmæ*; but it is more frequently found in irregular maſſes of a red, yellow, or blue colour. There are ſeveral mines of rock ſalt near *Northwich* in *Cheſhire*; the firſt of which was diſcovered, as they were boring for coal, in the year 1670*.

The ſprings which are met with, both *above* and *below* the level of the Northwich bed of rock ſalt, are

ſtrongly

* Philoſ. Tranſ. No. 66.

ſtrongly impregnated with ſalt. This is eaſily accounted for; the rain water, in ſinking through the ground which lies over the rock ſalt, at laſt arrives at the ſalt; its further deſcent is in a great meaſure obſtructed by the ſolid body of ſalt, it reſts upon it, and in reſting upon the ſalt it diſſolves it, and thus conſtitutes a brine ſpring above the level of the bed of rock ſalt. The brine ſprings, which are found below that level, probably ariſe from the water, which has diſſolved a portion of rock ſalt, in ſinking to that depth in the earth.

I have had the curioſity to go to the bottom of ſome of the moſt famous mines in England; ſuch as the copper mine at Ecton; the coal mines at Whitehaven and Newcaſtle; the cannel coal mines in Lancaſhire; and

a variety of lead mines in Derbyſhire, and other places; but I never thought my labour, in theſe ſubterraneous expeditions, ſo well rewarded, as in the ſight of the rock ſalt mines at Northwich. The ſalt mines at *Wiliczka* near *Cracow* in Poland, have long been a ſubject of admiration, and every traveller has exerted his deſcriptive talents, in magnifying the ſtupendous wonders which are there to be met with. Theſe mines have been wrought above five hundred years, and from that circumſtance we may readily imagine, the great number of vaſt caverns which have been formed in conſequence of the blocks of ſalt which have been annually extracted: yet it deſerves to be remarked, that the Northwich rock ſalt mines are ſuperior to thoſe

of Cracow, with reſpect to the quantity of ſalt which is annually raiſed. The ſingle pit into which I deſcended at Northwich, yielded at a medium 4000 tons of ſalt in a year; this quantity is about two thirds of that which is raiſed every year in the Poliſh mines here ſpoken of*.

A great quantity of rock ſalt is uſed at Northwich, in order to ſtrengthen their brine ſprings, and a much greater quantity is ſent coaſtways to Liverpool and other places, where it is uſed either for ſtrengthening brine ſprings or ſea water; much of this rock ſalt was formerly exported to Holland, and it is ſtill ſent to Ireland for the ſame purpoſe. Rock ſalt, and the white ſalt which is

* See Memoire ſur les Mines de Sel de Wieliczka, en Pologne, in Hiſt. de l'Acad. des Scien. à Par. 1762.

is at Northwich, chiefly made from rock salt, is exported free from the salt duty; and I was informed that the quantity which is annually exported from Northwich, is so great, that, if it paid the duty, it would bring in to government, a sum not much short of four hundred thousand pounds a year. "According to the best accounts I have been able to procure, the gross duty on salt made in South Britain, amounts annually to seven hundred thousand pounds.*" The duty on salt made at Northwich is about seventy thousand pounds a year, or a tenth part of the whole duty†.

The

* Camp. Sur. of Brit. Vol. II. p. 26.

† Since I received this information, an additional duty of 10d. a bushel has been laid, in 1780, on salt. The whole duty now amounts to

The Northwich rock ſalt is never uſed at our tables in its crude ſtate; and its application to the pickling or curing of fleſh or fiſh, or preſerving any proviſions, without its being previouſly refined into white ſalt, that is, without its being diſſolved in water, and boiled down into what is called white ſalt, is prohibited under a penalty of 40s. for every pound of rock ſalt ſo applied. The pure tranſparent maſſes, however, of rock ſalt, might, probably, be uſed by us with our food, without any ſort of danger or inconvenience; at leaſt, we know that rock ſalt is ſo uſed, without being refined, both in *Poland* and in *Spain*. In the laſt of theſe countries, at

to 4s. 2d. the buſhel, the buſhel weighing 56lb. The makers of ſalt can afford, in moſt places, to ſell their ſalt, exclusive of duty, from 8d. to 10d. a buſhel.

at *Cordona* in the province of *Catalonia*, there is a ſolid mountain of rock ſalt, between four and five hundred feet in height, and a league in circuit; its depth below the ſurface of the earth is not known*. This prodigious mountain of ſalt, which has no mixture of other matter with it, is eſteemed ſo ſingular an appearance, that it is thought to militate very much againſt the opinion of thoſe, who would derive the origin of all the beds of rock ſalt, which are found under the ſurface of the earth, from the evaporation of ſalt water, left in ſubterraneous caverns, either at the deluge, or upon ſome more local commotions of the globe.

The

* Hiſt. Nat. de l'Eſpag. p. 406. See an account of ſimilar mountains of rock ſalt in Shaw's Travels, p. 229, and in Pliny's Hiſt. Nat. l. xxxi. c. 7.

The quantity of rock ſalt which may be diſſolved in a definite quantity, ſuppoſe a pint or 16 avoirdupois ounces of water, is differently eſtimated by different authors. *Boerhaave* is of opinion, that 16 ounces of water will not diſſolve quite five ounces of rock ſalt*; *Spielmann* thinks that they will diſſolve 6⅖ ounces†; *Newmann* agrees with Spielmann‡; *Eller* ſays, that ſeven ounces of foſſile ſalt may be diſſolved in 16 ounces of water§; laſtly, *Hoffmann* aſſures us, that 16 ounces of water will not diſſolve above ſix ounces of common ſalt‖. I have tried this matter with diſtilled and with common water, and

* Chem. Vol. I. p. 476.

† Inſt. Chem. p. 48.

‡ Newmann's Chem. by Lewis, p. 256.

§ Obſ. Phy. Chem. L. ii. Ob. xvi.

‖ Ber. Mem. 1750.

and in various degrees of heat, and cannot but be of opinion, that Hoff-mann's experiment approaches nearest to the truth; I never could dissolve *quite** six ounces of rock salt in 16 ounces of water. It is not wholly improbable, that different sorts of rock salt may differ somewhat with respect to their solubility in water.

If it be admitted, that 16 ounces of water can dissolve six ounces of salt and no more, then we may be certain, that no brine spring, in any part of the world, can yield six ounces of salt from a pint of the brine. For brine springs are, ordinarily, nothing but water in which fossile salt has been dissolved; but a pint of the strongest brine cannot contain so much salt, as is contained in a pint of water, which has been saturated

with

with ſix ounces of ſalt; for a pint of water, in which ſix ounces of ſalt have been diſſolved, is increaſed a little in bulk, it will do more than fill a pint meaſure, and the ſalt left in the ſurplus will ſhew, how much the ſalt, contained in a pint of the ſtrongeſt brine, falls ſhort of ſix ounces. Or we may conſider the matter in the following manner, which will, perhaps, be more intelligible; 16 ounces of water, impregnated with ſix ounces of ſalt, conſtitute a ſaturated brine, weighing 22 ounces; if therefore we would know how much ſalt is contained in 16 ounces of ſuch brine, by the rule of proportion we may argue, that if 22 ounces of brine contain ſix ounces of ſalt, 16 ounces of brine will contain $4\frac{4}{11}$ ounces of ſalt. Hence we may infer, that the

ſtrongeſt

ſtrongeſt brine ſprings will not yield much above one quarter of their weight of ſalt*.

Dr. Leigh, who firſt ſhewed the manner of refining rock ſalt, informs us, that ſome of the ſtrongeſt ſprings at Northwich, gave ſeven or eight ounces of ſalt from a quart of brine; but a quart of brine weighs conſiderably more than 32 ounces, the weight of a quart of water; ſo that the Northwich ſprings, from this account,

* ——— "Several pits at *Northwich*, and at *Barton* in *Lancaſhire*, contain no leſs than ſix ounces of ſalt upon ſixteen of brine; which is as large a proportion of ſalt as water will diſſolve." Newm. Chem. p. 212, Lewis's note. The author here is fallen, probably, into a little miſtake, by confounding a pound of water with a pound of brine; for if a pound or 16 ounces of water will only diſſolve ſix ounces of ſalt, a pound of the brine, thus formed, will only hold 4 $\frac{4}{11}$ ounces of ſalt.

count, do not yield a quarter of their weight. At *Middlewich* there is said to be one salt spring, which is stronger than the rest; this spring yields a *full fourth* part of salt*, and hence it is, probably, fully saturated. We have an account in Kircher's works, of some famous brine springs in *Burgundy*, from which we learn, that one hundred pounds weight of the strongest brine gave 25 pounds, or just one *fourth* of its weight of white salt †.

There are a great many brine springs in *Cheshire*, *Worcestershire*, *Staffordshire*, *Hampshire*, and in other parts of Great Britain, some of which are sufficiently rich in salt to be wrought with profit, others not.

From

* Philos. Trans. No. 53.

† Kirch. Mun. Sub. Tom. II. Cap. XI.

From what has been before advanced the reader will readily comprehend that 16 tons of the ſtrongeſt brine conſiſt of 12 tons of water, and of 4 tons of ſalt; and that, in order to obtain theſe 4 tons of ſalt, the 12 tons of water muſt be, by ſome means or other, evaporated, ſo as to leave the ſalt in a concrete form. Suppoſe there ſhould be a brine, which in 16 tons ſhould contain 15 tons of water, and only 1 ton of ſalt; yet it may chance, that ſuch a weak brine may be wrought with more profit than the ſtrongeſt; for the profit ariſing from the boiling of brine into ſalt, depends as much upon the price of the fuel uſed in boiling it, as upon the quantity of ſalt which it yields. Thus the ſea water, which ſurrounds the coaſts of Great Britain, is ſaid to

hold

hold ſeldom more than one thirtieth, or leſs than one fiftieth part of common ſalt; but fuel is ſo cheap at Newcaſtle, that they can evaporate thirty or forty tons of water, in order to obtain one ton of ſalt, and yet gain as much clear profit as thoſe do, who, in counties leſs favourably ſituated for fuel, boil down the ſtrongeſt brine.

The advantage reſulting from ſtrengthening weak brine or ſea water, by means of rock ſalt, is very obvious. Suppoſe that the ſea water at Liverpool, where large quantities of rock ſalt are refined, would yield 1 ton of ſalt from 48 tons of water, then muſt a quantity of fuel ſufficient to evaporate 47 tons of water be uſed in order to obtain 1 ton of ſalt. But if as much rock ſalt be

put into the 48 tons of ſea water, as can be diſſolved in it, then will the ſea water reſemble a brine fully ſaturated, each 16 tons of which will give 4 tons of ſalt, and the whole quantity yielded by the evaporation of 47 tons of water, will be 12 tons of ſalt.

In warm climates, ſuch as *Italy*, *Spain*, and the ſouthern provinces of *France*, where the heat of their ſummer is ſufficient to exhale conſiderable depths of water in a little time; they prepare large quantities of what is called *bay ſalt*, at a very ſmall expence. Their general method is to ſelect a marſhy ſpot of ground, communicating by ſluices with the ſea, and ſufficiently removed from freſh ſprings, and the mouths of large rivers. In this ground they form

usually three pits of small but different depths, and by clay and timber they secure them from leaking. The sea water is let into the first and deepest pit, from which it flows slowly, so as to give the mud and sand time to settle, through the second into the third, where it is soon inspissated by the heat of the sun into a strong brine. This brine being still further evaporated by the continued action of the sun, concretes into crystals of salt, which gradually sink to the bottom of the pit. When a proper quantity of it is formed, it is drawn out for use, and is of different colours, according to the colour of the clay employed in making the pits. In a favourable season, the French are said to be able to make enough of bay salt in a fortnight, to

ſupply their home conſumption for a year, and the wants of the other nations, who purchaſe from them much more than is conſumed in France*.

In this method of making bay ſalt, art has but copied nature: for we read in Pliny, Alonſo Barba, Shaw, and others, of large briny lakes, which are evaporated, in many parts of the world, to a perfect dryneſs in ſummer time; when the inhabitants cut and carry away as much ſalt as they have occaſion for. A remarkable lake of this kind was met with by Mr. Maſſon, in his botanical excurſions from the Cape of *Good Hope.* "*Zwart Kop*'s ſalt-pan is a lake ſeveral

* See Dr. Brownrigg's Treatiſe on the Art of making common Salt, where the reader's curioſity on this ſubject will be abundantly gratified.

veral miles diſtant from the ſea, and upon an eminence. In the rainy ſeaſon it is filled with freſh water, which, by the ſaltneſs of the ground, ſoon becomes ſtrongly impregnated with ſaline particles; and when the ſummer's heat exhales the freſh water, the bottom of the lake is covered with a cruſt of pure ſalt two or three feet thick. The lake is about three miles round, and ſurrounded by a riſing ground *."

Though it appears, from what Dr. *Brownrigg* has ſaid upon this ſubject, that we might, with much advantage to our trade, imitate the French in their manner of procuring bay ſalt; yet moſt of our ſalt is prepared by boiling either the brine of ſalt ſprings, or ſea water, into white ſalt.

* Philoſ. Tranſ. 1776, p. 297.

ſalt. In Hampſhire, and ſome other counties, they have a method of heightening the ſea water into a ſtrong brine, by expoſing it to the ſun in large pits, much after the manner in which bay ſalt is made; and ſo much of the ſea water is, by this means, naturally evaporated, that though they boil the remainder with Newcaſtle coal, yet they can afford their ſalt at a leſs price than the Newcaſtle ſalt boilers can afford theirs; though the ſea water is, probably, equally impregnated with ſalt at both places.

The greateſt difficulty which attends the making of bay ſalt in Great Britain, ariſes from the heat of our ſummer not being ſufficiently ſtrong, to evaporate a great quantity of ſea water in a ſmall portion of time. I

will

will mention an experiment or two, which ſuggeſted a hint, that may not, perhaps, be unſerviceable to thoſe who ſhall, in future, be diſpoſed to attempt the making of bay ſalt.

I took a piece of coarſe linen cloth, its area was a ſquare yard, and having thoroughly wetted it with water, but not ſo much as to cauſe it to drip, I weighed it, and in that wet ſtate expoſed it to a warm ſun in June, when there happened to be but little wind; it was not laid upon the ground, but held oppoſite to the ſun, ſo that the air and ſun had a free acceſs to every part of it; it became nearly dry in an hour, and in that ſpace of time it had loſt eight ounces of its weight. — Upon another occaſion, when there was a bright ſun and a briſk wind,

wind, on an April day, a ſimilar experiment was made; and the cloth loſt after the rate of 6 ounces in one quarter of an hour; hence, if it had been kept conſtantly wetted, it would have loſt in 16 hours 24 pounds; a pound of water is equal to a pint in meaſure; and therefore we may infer, that in a ſummer day of 16 hours in length, 24 pints, or three gallons of water may be diſperſed into the air, by a warm ſun and a briſk wind, from the ſurface of a linen cloth, equal to one ſquare yard.

Now it is very poſſible, in any place where bay ſalt is made, to deviſe means of wetting and drying alternately any number of ſquare yards of coarſe cloth; one labourer, aſſiſted by proper mechanical contrivances, might be equal to the daily manage-

ment

ment of a thouſand yards, or more. By this plan, in favourable weather, there would be daily evaporated twenty-four thouſand pounds of water, which, ſuppoſing ſea water to contain one thirty-ſecond part of its weight of ſalt, would give 750 pounds of ſalt. Thoſe who have ſeen the artifice of ſtrengthening brine, which is practiſed in *Franche-Comté*, and other places, by making it drip through faggots, in order that the evaporation may be increaſed, by increaſing the ſurface of the water which is expoſed to the air, will not be ſurpriſed at the method of evaporating water here hinted at.

Though the conſtituent parts of common ſalt, when free from all heterogeneous mixtures, are probably the ſame in every part of the world,

yet

yet in the ordinary ſtate in which it is met with, it is found to have very different qualities, and may properly enough be divided into different ſorts. Bay ſalt differs in ſome of its properties from the white ſalt, prepared by boiling brine or ſea water; and both the bay ſalt and the boiled ſalt have, reſpectively, different qualities, according as they are prepared at different places. There are two general reaſons of this diverſity; one reſpects the manner of preparing the ſalt, the other reſpects the quality of the water from which the ſalt is prepared. When ſea water or brine is boiled into ſalt, a portion of the acid, which is one of the conſtituent parts of the ſalt, is diſperſed; and a greater or leſs portion is diſperſed, according as the ſalt has been formed

with

with a greater or leſs degree of heat. We have an inſtance of this, both in bay ſalt when compared with boiled ſalt, and in the different ſorts of boiled ſalt when compared with each other. Bay ſalt is prepared from ſea water, by the mild heat of the ſun, and it is generally eſteemed much ſtronger than the white ſalt, which is prepared likewiſe from ſea water by boiling the ſea water. At Northwich, and in other places, they prepare from brine, not only the ordinary white ſalt, but a ſalt whoſe cryſtals are much larger than the ordinary ſalt, and which is uſually called ſhivery ſalt. This ſhivery ſalt is eſteemed ſtronger than the other, and it is formed by a milder heat; for in forming the ordinary ſalt, the brine is kept gently boiling; but in forming

forming the large-grained ſhivery ſalt, they let the brine cool till they can bear to put their hands into it, and keeping it in that ſtate, as near as may be, from Saturday night to Monday morning, the ſhivery ſalt is gradually formed. Sea water, brine ſprings, and rock ſalt, generally contain, beſides common ſalt, various other earthy and ſaline ingredients, ſuch as the *calcareous earth* from which fiſh-ſhells are probably formed;—the earth called *magneſia*;—*Epſom ſalts*, or the ſalt reſulting from the combination of the acid of vitriol with magneſia;—*Selenites*, or the ſalt reſulting from the combination of the acid of vitriol with the earth of the nature of fiſh ſhells;—*Glauber's ſalt*;—*fixed alkali* uncombined with any acid, &c. Sometimes all theſe

hetero-

heterogeneous ſubſtances, and ſometimes only a few of them are found in the waters from which common ſalt is prepared; they are all of them foreign to the nature of the ſalt, and injure its quality; and hence we may, without difficulty, comprehend that common ſalt may have very different properties, according to the quality of the water from which it is made, or the ſkill of the ſalt-maker exerted in ſeparating theſe mixtures from it. The *Dutch* have long been famous for preparing a ſalt for the pickling of herrings, by which they have acquired a ſuperiority in that article of commerce over all other European nations. Their principal ſecret in this buſineſs conſiſts in evaporating the brine made from the ſolution of

of bay falt with the gentleft fire, and in mixing with the brine a proper quantity of very *four whey*; the acid whey unites itfelf with the uncombined fixed alkali before mentioned, and thus prevents it from adhering to the common falt as it cryftallizes. Any other mild acid might probably anfwer the fame purpofe. This acid whey is called *azy*: les Hollandois fe fervent de l'*azy* dans le travail en grand pour raffiner nos fels de mer, et pour en rendre la criftallifation parfaite; c'eft par cet artifice qu'ils font depuis long-temps, en poffeffion de fournir les meilleures falaifons de l'Europe*

* Hift. de l'Acad. de Scien. 1762. Dr. Brownrigg had mentioned this fecret of the Dutch above 30 years ago, in his excellent treatife before referred to. The reader will

meet

meet with an accurate examination of the various ingredients with which common salt, and the waters from which it is made, are impregnated in Baumé's Chem. vol. iii. p. 512.

ESSAY III.

OF COMMON SALT AND NITRE AS MANURES.

COMMON ſalt, in the earlieſt ages of the world, was ſo far from being held in any eſtimation as a manure, that it was looked upon as a ſymbol of extreme ſterility. Long before the commencement of profane hiſtory, *Abimelech* took the city *Shechem*, and *ſlew the people that was therein, and beat down the city, and ſowed it with ſalt** ; intimating thereby

* Judges ix. 45.

by his wiſh that it might remain un-fruitful and uninhabited for ever.

It does not appear from hiſtory, what circumſtance gave riſe to this cuſtom, or whether Abimelech was the firſt perſon who introduced it; but it has prevailed very generally among mankind even to the preſent age, it being ſtill uſual to raze the houſes of rebels and traitors, and to ſprinkle the ground upon which they ſtood with ſalt. Perhaps this general ſymbolical uſe of ſalt, might be derived from what had hap-pened when *Sodom* was deſtroyed, and the *ſalt ſea* was formed. This conjecture is, in ſome meaſure, ſup-ported by obſerving, that the ſevereſt denunciations of divine vengeance are frequently expreſſed by an allu-ſion to that event—*Moab ſhall be as*

 Sodom,

Sodom, and the children of Ammon as Gomorrah, even the breeding of nettles, and salt pits and a perpetual desolation *. *The whole land thereof is brimstone, and salt, and burning, that it is not sown, nor any grass groweth therein, like the overthrow of Sodom* †.

Virgil reprobates a salt soil, as occasioning the degeneration of fruit trees, and admitting no melioration from ploughing.

Salt earth and bitter are not fit to sow,
Nor will be tam'd or mended with the plough.
Sweet grapes degenerate there, and fruits, declin'd
From their first flav'rous taste, renounce their kind ‡.

Pliny,

* Zephaniah, ii. 9.
† Deuteron. xxix. 23.
‡ Virgil's Georg. l. 2. Dryd.

Pliny, though he recommends the giving of ſalt to cattle, yet in ſpeaking of foſſile ſalt, he expreſsly affirms, that every place in which it is found, is barren and unfit for vegetation*.

Notwithſtanding theſe and other teſtimonies of the ancients concerning the ſterilizing quality of common ſalt, yet it is frequently uſed as a manure with great ſucceſs. It has been the cuſtom, ever ſince the time of Henry the Third at leaſt, for the farmers on the *Corniſh* coaſt, to manure their lands with ſea ſand, in which ſea ſalt is ſo copiouſly mixed, that in many places it uſed to be extracted from a lye made of ſand. When the ſand has been long expoſed to the air, it proves leſs uſeful and

* Hiſt. Nat. L. xxxi c. 7.

and enriching, which is by ſome attributed to its having been deprived of a good part of its ſalt, by the dews and rains*. It may be obſerved, that this ſand is of two kinds, ſhelfy and ſhelly; the ſhelfy is produced from the grating of ſtones one againſt another, by the conſtant waſh of the ſea, and is of little value; its quality, however, will be different in different countries, according to the nature of the ſtones expoſed to the agitation of the ſea; if the ſtones happen to be of the limeſtone kind, even the ſhelfy ſand may be very ſerviceable; if the ſtones principally conſiſt of flint, as at Yarmouth, and other parts of the Norfolk coaſt, the ſand will differ very little from powdered flints. The ſhelly ſand in Cornwall is

* Camden's Britan. Cornw.

is produced by the ſame fluctuation of the ſea, as the flinty ſand in Norfolk; it conſiſts of the broken ſhells of muſcles, cockles, oyſters, ſcollops, and other fiſh. This ſand varies ſomewhat in colour and in grain, according to the ſubſtances from which it is formed, and the degree of agitation it has been expoſed to, and it is found to fertilize almoſt all kinds of ſoils*. This practice of manuring lands with ſea ſand, has, within theſe few years, been introduced with great ſucceſs in other parts of Great Britain.

The *Cheſhire* farmers purchaſe no inconſiderable quantity of refuſe ſalt from the ſalt boilers; they mix it with dung, and it makes an excellent manure. This refuſe ſalt coſts them

eight-

* Philoſ. Tranſ. No. 113.

eightpence a buſhel, there being a duty of fourpence a buſhel impoſed on it. When the demand for this refuſe ſalt is very great, the ſalt boilers have a cuſtom to mix a quantity of ſoot, or other impurity, with the ordinary ſalt, and it then comes under the denomination of refuſe ſalt; there were ſold a few years ago at Northwich alone, near 3000 tons of it in one year, for the uſe of the farmers in that and other counties. On the other hand, when the ſoil abounds with ruſhes and weeds, it is cuſtomary in Cheſhire, to lay a quantity of rock ſalt upon it, as it is found utterly to deſtroy every vegetable. Hence it ſhould ſeem, that ſalt, when uſed in ſmall quantities, is a good manure, and when in large ones, a real poiſon to vegetables. Some of the African and

Arabian

Arabian deſerts are thought to be barren by their having too much ſalt in them; whilſt many parts of Barbary are reckoned to be peculiarly fruitful, from their containing a leſs quantity of it*.

Sir *John Pringle* has obſerved, that common ſalt, when uſed in ſmall quantities, as one ounce to twelve, accelerates the putrefaction of animal ſubſtances, when in larger it retards it; and hence he deduces its utility, in aſſiſting the organs of digeſtion in man, and, perhaps, in other carnivorous animals†. The ſame obſervation may be extended to graminivorous animals, they are all exceedingly fond of ſalt, probably from

* Brownrigg on Salt, p. 159.

† Obſerv. on the Diſeaſes of the Army, by Sir J. Pringle, Appen. xxxix.

from its great tendency to corrupt the aliment, and to render thereby its discharge from the stomach into the intestines, more easy and expeditious.

In like manner, salt, when applied as a manure, in small quantities, is found to be very beneficial; not probably from its entering as an aliment into the substance of vegetables, since there are many experiments tending to prove that no kind of salt can of itself become the food of plants*, but

* Wallerius expressly says — Les sels de quelle espece qu' ils soient, *ne peuvent pas servir de nourriture aux plantes, ni avancer par eux-memes la vegetation*; and after quoting the experiments of Krastius, Alston, and Bonnet, on the subject, and examining the arguments on the opposite side of the question, he concludes the inquiry in the following words:

but from its efficacy in reducing weeds, dried herbage, dead roots, &c. into a putrid oily mass; the fructifying virtue of oily composts being now generally acknowledged: but when it is used in a larger proportion, by preserving these matters from corruption, and drying up or hardening the fibrous capillaries of the roots, so that they become unfit for sucking in nutriment, the fertility

words:—D'où nous concluons que les sels minéraux, ni les sels étrangers, ni les terres minérales, ne contribuent point à la nourriture des végétaux. Elemens d'Agriculture traduits du Latin de M. Wallerius. Yverden, 1766, p. 134, &c. or an English translation of the same work, by John Mills, Esq. F. R. S. London, 1770. See also the Principles of Agriculture and Vegetation, by Dr. Home; and the elements of Agriculture, by Dr. G. Fordyce.

ity of the ground is diminiſhed, or wholly deſtroyed.

As to the fertility of lands overflowed by ſea water, it may be in part owing to the ſlime and mud left by it, and partly to the ſalt contained in it, which, being in a ſmall quantity, may contribute to the putrefaction of the effete vegetable roots, and the conſequent production of an oily compoſt.

With reſpect to nitre as a manure, it is an opinion entertained by farmers, that ſnow fertilizes the lands upon which it falls, more than rain, in conſequence of the nitrous ſalts which it is ſuppoſed to acquire by freezing. Falſe philoſophy firſt gave riſe to this idea*, and poetry has con-

* Gaſſend. Phyſ. ſec. iii. l. 11. The exiſtence

contributed to ſpread the general error.

——Oh! may'ſt thou often ſee
Thy furrows whiten'd by the woolly rain
Nutritious, ſecret *nitre* lurks within
The porous wet, quick'ning the languid
glebe.

PHILIPS.

' What art thou froſt?——
Is not thy potent energy, unſeen
Myriads of little *ſalts*, or hook'd or ſhap'd
Like double wedges, and diffus'd immenſe
Thro' water, earth, and ether?

THOMPSON.

The

iſtence of nitre in ſnow, and the fertilizing quality of ſalts, were ſo generally admitted in the laſt century, that philoſophers ſeem to have been at no pains to prove either of them. — On *ſait* que la *neige* contient beaucoup de parties *nitreuſes*, et que les *ſels* contribuent beaucoup à la *fecondité* des terres. Actes de Copenhagne, Collect. Acad. vol. vi. p. 195.

The ancients were acquainted with the fertilizing quality of snow, and though they did not very intelligibly explain its mode of operation in promoting vegetation, yet it is remarkable, that the supposition of saline corpuscles made no part of their illustration of that matter*. It is not here intended to deny the fertilizing virtue of snow, but to shew that it probably does not proceed from the nitre contained in it; in support of this opinion, I will mention two of the most accurate experiments, which have probably ever been made on the subject.

Marggraaf, in the year 1751, collected in the suburbs of Berlin as much snow as, when melted, afforded him one hundred measures of water,

* Plin. Hist. Nat. l. xvii. c. 2.

water, each meaſure containing thirty-ſix ounces*. He collected the ſnow in an open ſituation, in clean glaſs veſſels, after the atmoſphere was purified, by its having ſnowed ſome time; in ſhort he uſed every poſſible precaution to procure the ſnow free from every extraneous impurity. The nitrous or other ſalts contained in the ſnow as it fell upon the ground were, no doubt, diſſolved in the water after the ſnow was melted; and, in order to aſcertain their quantity and quality, nothing more was requiſite than to diſſipate, by evaporation or diſtillation, the water in which they were diſſolved. From theſe hundred meaſures of ſnow water he obtained, by diſtilling it with every ſuitable attention, 60 grains, not

* Opuſ. Chy. vol. ii.

not of *nitre*, but of *calcareous earth*, together with ſome grains, he does not mention the exact number, of the acid of ſea ſalt, impregnated with a nitrous vapour.

The ſame quantity of rain water, collected in the winter months with equal precaution, and diſtilled with equal attention, yielded 100 grains, not of *nitre*, but of *calcareous earth*, with ſome grains of the acids of nitre and ſea ſalt*.

The

* Toute la difference donc entre l'eau de pluie et l'eau de neige n' eſt d' aucune importance, et ſe reduit à ce que l' acide de l'eau de pluie eſt plus *nitreux*, et qu' elle renferme plus de terre calcaire, au lieu que l' eau de neige a plutôt un acide *marin que nitreux*, et contient une moindre quantité de terre calcaire. Opuſcules Chymiques, vol. ii. p. 21.

The author infers from theſe experiments, that the chemical difference between rain and ſnow water is exceedingly ſmall; but that the latter, however, is ſomewhat leſs nitrous, and contains a ſomewhat leſs proportion of earth than the former. But neither of them contains either earth or any kind of ſalt in any quantity, which can be ſenſibly efficacious in promoting vegetation.

Suppoſe an acre of land to be, at any one time, covered with ſnow to the depth of ſix inches; and that this ſnow would, when melted, be reduced in magnitude a ſixth part, or that it would cover the land with water to the depth of one inch; then might it be made appear, by a very eaſy calculation, that allowing 60 grains of calcareous earth to every

28 gal-

28 gallons and one pint of water, according to the proportion of the foregoing analyſis, the whole of the earth left upon the acre from the evaporation of the ſnow water, would not amount to ten pounds in weight; nor the ſaline part to above a few ounces. Now it is very improbable that four or five ounces of any kind of ſalt, when ſpread over an acre, ſhould produce any ſenſible effect in fertilizing the ground. And if we ſuppoſe the land to be ſo often covered with ſnow in the courſe of a year, that the ſalt left upon it would amount even to a pound, yet the difficulty would ſtill recur, ſince even a pound of ſalt reduced to an uniform pellicle, and ſpread over an acre of land, would not much exceed in thickneſs, the four hundred

 thouſandth

thoufandth part of an inch. So that if it fhould be admitted that nitre is a fertilizer of land, which many are, upon good grounds, difpofed utterly to deny, yet fo very fmall is the quantity of it contained in fnow, that it cannot be fuppofed to promote the vegetation of plants upon which the fnow has fallen.

The peculiar agency of fnow as a fertilizer, in preference to rain, may admit of a very rational explanation, without having recourfe to any nitrous falts, which it has been fuppofed to contain. There are two caufes conftantly acting upon the furface of the earth, one of which is, generally fpeaking, uniform in its ftrength with refpect to the production of heat; the other is variable. The internal fubftance of the earth

is heated uniformly, by ſome principle or other which we do not well underſtand, to the 48th degree of Fahrenheit's thermometer; this degree of heat is greater than that in which the watery juices of vegetables freeze, and it is propagated from the inward parts of the earth to the ſurface on which the vegetables grow. The atmoſphere being variably heated, by the variable action of the ſun in different climates, and in the ſame climate at different ſeaſons, communicates to the ſurface of the earth, and to ſome diſtance below it, the degree of heat or cold which prevails in itſelf. Different vegetables are able to preſerve life under different degrees of cold; but all of them periſh, when the cold which reaches their roots is extreme. Provi-

 dence,

dence, in the coldeſt climates, has provided a covering for the roots of vegetables, by which they are protected from the influence of the atmoſpherical cold; that *covering* is *ſnow*. Even in our climate we often ſee ſhrubs, and other ſmall vegetables, killed by the ſeverity of a froſt, when it is unaccompanied with ſnow, which, had there been eight inches, or a foot of ſnow upon the ground, would have remained unhurt. The ſnow keeps in the internal heat of the earth, and it does not permit the cold of the atmoſphere to penetrate through its ſubſtance, and on both theſe accounts it keeps the roots of the vegetables, comparatively ſpeaking, warm; a kind of vegetation is carried on under its ſurface, which ſhews itſelf by the very rapid increaſe

which

which plants of all kinds acquire in cold countries, as ſoon as the covering of ſnow is removed by the approach of ſpring. Thoſe who are fond of making oil the food of plants, may derive part of the utility of ſnow in fertilizing the earth from the oily particles which it contains; for not only the reſidue which was obtained from the diſtillation of ſnow water, had a brown colour proceeding from ſome oily particles, but it is very commonly obſerved that ſnow, as it thaws, becomes dirty; and this dirty appearance is probably enough referred to ſome particles of an oily or a mucilaginous ſubſtance contained in it. Snow, moreover, in melting, moiſtens and pulverizes the ſoil, which had been bound up

by the froſt; and as its water has a tendency to putrefaction, it ſeems, on many accounts, without admitting it to contain any nitre, to be admirably fitted to promote vegetation.

In confirmation of the analyſes of rain and ſnow water which were made by Marggraf, I will here add thoſe which we owe to the accurate induſtry of Dr. Rutty*.—He evaporated ſix different ſpecimens of the pureſt rain water he could procure, and found that a gallon of the pureſt yielded ſix grains, and a gallon of the moſt impure 12 grains of a ſubſtance, for the moſt part, of a dark brown colour, and a *bitter, brackiſh* taſte. From a gallon of ſnow water, he obtained 4 grains of a browniſh reſidue, which conſiſted partly

* Rutty's Synop.

partly of *sea salt*, partly of an absorbent earth, and a small portion of oil.

It may be observed from these experiments, compared with those of Marggraf, that the proportion between the solid impurities of rain and snow water, is much the same, in parts of the globe as far distant from each other as *Ireland* and *Prussia*. Dr. Rutty's experiments were made in Dublin; a gallon of the purest rain water gave him 6 grains, the same quantity of the purest snow water gave him 4 grains of heterogeneous matter; now the proportion of 6 to 4, is not very different from that of 100 to 60, which expresses the proportional quantities of the residues left, from the evaporation of rain and snow

water, according to the experiments of Marggraf.

No two authors perfectly agree in aſcertaining the quantity of ſolid impurity contained in a definite portion of either rain or ſnow water; this is not to be wholly attributed to the difference of their care and ſkill exerted in the analyſis of them, but principally to the different natures of the ſubjects themſelves, upon which their labours have been employed. The vapours which are daily raiſed from the ſea, may, with great probability, be ſuppoſed to carry with them ſome minute portions of the acid of ſea ſalt, and, perhaps, of ſea ſalt in ſubſtance, and of the calcareous earth, with which the ſea abounds. The atmoſphere itſelf may be looked upon, not only as the general receptacle

ceptacle of theſe aqueous vapours, but likewiſe of all mineral exhalations; of the ſteams, which are conſtantly ariſing from the perſpiration of whatever enjoys animal or vegetable life; and from the inſtantaneous putreſcence of thoſe ſubſtances, when deprived of life; of the ſmaller ſeeds of terreſtrial and aquatic plants; of the eggs of an infinity of ſpecies of imperceptible animalcules; of the acids and oils ſeparated by combuſtion from all ſorts of fuel; of the matter of light; of electric effluviums; and of a variety of other ſubſtances, which are elevated, and for a time kept ſuſpended, by natural and accidental cauſes: from theſe ſources are derived, thoſe various impurities, which have been diſcovered in all atmoſpherical water; and

which, we can readily apprehend, muſt be different in quality and quantity, according to the nature of the heterogeneous ſubſtances ſubſiſting in that portion of the atmoſphere, through which the aqueous vapours have aſcended, or which they have waſhed in their deſcent; that is, in general, according to the nature of the climate, the ſeaſon of the year, the direction of the winds, and the preceding temperature of the weather.

ESSAY

ESSAY IV.

OF THE SALTNESS AND TEMPERATURE OF THE SEA.

THERE are few questions, respecting the natural history of our globe, which have been discussed with more attention, or decided with less satisfaction, than that concerning the primary cause of the saltness of the sea. The solution of it had perplexed the philosophers before the time of Aristotle*; it surpassed

* Arist. Meteo. L. ii. c. iii.

passed his own great genius; and those of his followers, who have attempted to support his arguments, have been betrayed into very ill-grounded conclusions concerning it. Father Kircher*, after having consulted three and thirty authors upon the subject, could not help remarking, that the fluctuations of the ocean itself were scarcely more various, than the opinions of men concerning the origin of its saline impregnation.

The question does not seem capable of admitting an illustration from experiment; at least, no experiments have hitherto been made for that purpose, and therefore we may be the less surprised at its remaining nearly as problematical in the present age, as it has been in any of the preceding.

* Kirch. Mun. Subter. L. iii. c. iii.

ceeding. Had there, indeed, any obſervations been made, three or four centuries ago, aſcertaining the then ſaltneſs of the ſea, at any particular time and place; we might, by making, at preſent, ſimilar obſervations at the ſame place, in the ſame ſeaſon, have been able to know whether the *ſaltneſs*, at that particular place, was an *increaſing*, or a *decreaſing*, or an *invariable* quantity: and this kind and degree of knowledge would have ſerved as a clue to direct us to a full inveſtigation of this matter in general; but it is to be regretted, that no ſuch obſervations have, till very lately, been made with any tolerable preciſion.—There are three principal opinions on this ſubject, which have been maintained by philoſophers of modern date.

Some

Some* obſerving that river water, almoſt in every part of the globe, is, in a greater or leſs degree, impregnated with ſea ſalt, have thought that the ſea has gradually acquired its preſent quality of ſalt from the long continued influx of rivers. The water, which is carried into the ſea by the rivers, is again ſeparated from it by evaporation, and being diſperſed over the atmoſphere by the winds, it ſoon deſcends in rain or vapour upon the ſurface of the earth; from whence it haſtens to pour into the boſom of the ocean, the freſh tribute of ſalt, which it has collected in its inland progreſs. Thus the ſalt conveyed into the ſea, not being a volatile ſubſtance, nor performing an inceſſant circulation, like the wa-

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* Halley, Philoſ. Tranſ. No. 344.

ter which carries it thither, must be a perpetually increasing quantity, and time enough, it is contended, has elapsed since the creation, for the sea to acquire from this source its present quantity of salt.

The principle upon which this opinion is founded, cannot become the subject of accurate calculation; rivers may have formerly carried more or less salt into the sea, than they do at present; and the quantities, contained at present in different rivers, are so various, that any general position, with respect to the proportion of salt observable in river water, will be liable to many exceptions from particular cases. It may appear probable, however, from the following observation, that the cause here assigned of the saltness of the

ſea, is not adequate to the effect. Sea water, at a medium taken from obſervations made in different climates, may be ſuppoſed, without any great apprehenſion of error, to contain about one thirtieth of its weight of common ſalt; but all the rivers in the world could not have conveyed into the ſea one five hundredth part of the weight of the ſea, though we ſuppoſe that they have daily, ever ſince the creation, carried into the ſea and left there, the ſame quantity of ſalt, which they do at preſent daily depoſit in it. In order to make this out, with any appearance of perſpicuity and preciſion, we will take for granted, what ſome eminent philoſophers have endeavoured to prove,—" that all the rivers in the world flowing into the

bed

bed of the sea, with a continuance of their present stores, would take up at least eight hundred years to fill it to its present height *;"—this being premised, let us suppose the ocean to have been originally quite fresh, and to have daily lost by evaporation as much water, as it daily received from the influx of the rivers, then must eight hundred years have passed before the fresh water of the ocean could have been changed into river water, or acquired that proportion of salt with which river water is impregnated. River water may, in general, be supposed to contain one four thousandth part of its weight of sea salt; some rivers, doubtless, contain

* Goldsmith's Hist. of the Earth, &c. Vol. I. p. 228. Buffon, Hist. Nat. Vol. I. p. 356.

tain more, others leſs, but the quantity here aſſumed ſeems to be great enough; ſince even the Thames* water, taken up near Billingſgate, impregnated, as it may be ſuppoſed to be, with ſea ſalt, from the quantity of it uſed in London, and waſhed into it by various drains, does not contain one half ſo much; the ocean upon this hypotheſis, at the expiration of eight hundred years from the creation, would have contained one four thouſandth part of its weight of ſea ſalt; and at the expiration of eight times eight hundred years, it would have contained eight four thouſandth parts, or one five hundredth part of its weight of ſalt; but eight times eight hundred years carry us

* See an ingenious Inquiry into the Nature of Water, by Dr. Rotherham, p. 114.

us back to an æra antecedent to the creation of the world.

Other philoſophers *, obſerving that large beds of foſſile ſalt are not unfrequent in any quarter of the globe; and conceiving, with great probability, the bottom of the ſea to be analogous in its formation to the ſurface of the earth, have undertaken to derive its ſaltneſs from the beds of rock ſalt, which they have ſuppoſed to be ſituated at its bottom; and they are further of opinion, that without ſuch a permanent ſaline principle, the ſea would long ſince have become inſipid from the freſh water poured into it by an infinity of rivers. Strange! that what,

* Mem. de l'Acad. des Scien. de Ber. Ann. 1760.

what, according to the forementioned hypothesis, was thought sufficient to account for the saltness of the sea, should in this be esteemed instrumental in annihilating the saltness already supposed to exist.

This opinion is liable to an objection of some weight; for it may reasonably be inquired, why the waters of the ocean are not perfectly saturated with salt, if they have ever since the creation been exerting their dissolving powers upon such permanent masses of rock salt as are thought to be situated at its bottom. Were the waters of the ocean in a quiescent state, and every where of two or three miles in depth, as they are conjectured to be in some, it would not be an easy matter to define the time in which the waters at

the

the surface would become sapid, much less, in which they would become saturated, though the whole bottom of the ocean was covered with a stratum of rock salt. The water contiguous to the salt would saturate itself therewith, and being thereby rendered heavier than the superficial water, it would not readily mix itself with it; but though the lower parts of the sea have been observed by divers to remain in a very tranquil state, when the upper have been much agitated by storms; yet it may reasonably be supposed, that they are sufficiently moved, to cause, in a sufficient length of time, an uniform diffusion of the rock salt, they may be supposed to have dissolved. The patrons of this opinion found their reasoning upon a mistake;

they think, that if there were no mines of rock ſalt in the bed of the ocean, its waters would have been long ago converted into freſh water, by the rivers diſcharged into it. Now this is an erroneous principle; for ſuppoſing that the rivers themſelves contained no ſalt, and that they returned into the ſea, in any given time, the ſame quantity of water, which in the ſame time is raiſed from it by evaporation, the ſaltneſs would remain preciſely the ſame for ever. But neither of theſe ſuppoſitions is true, for the rivers do convey into the ocean ſome portion of ſalt every day, and they do not, in any given time, return into the ocean ſo much water as in the ſame time is ſeparated from it; and upon both theſe accounts, the ſalt-

neſs

ness of the ſea, ſo far from being diminiſhed, ought conſtantly to be increaſed, from the rivers poured into it.

Boyle * unites, as it were, the two preceding hypotheſes, and "takes the ſaltneſs of the ſea to be ſupplied, not only from rocks and other maſſes of ſalt, which at the beginning were, or in ſome countries may yet be found either at the bottom of the ſea, or at the ſides, where the water can reach them; but alſo from the ſalt which the rivers, rains, and other waters diſſolve in their paſſage through divers parts of the earth, and at length carry with them into the ſea." Buffon †, and the generality

* Boyle's Works, Vol. III. p. 381.

† Hiſt. Nat. Vol. I. p. 361. Goldſmith's Hiſt. of the Earth, Vol. I. p. 234.

rality of philosophers, acquiesce in the opinion of Boyle.

After all, it may be observed, that we are inquiring into the cause of a phænomenon, which it may be said had no secondary cause at all. It is taken for granted in this disquisition, that the water which covered the globe in its chaotic state, was not impregnated with salt as at present, but quite fresh; now this is an opinion concerning a matter of fact, which can never be proved either way; and surely we extend our speculations very far, when we attempt to explain a phænomenon, primeval to, or coeval with, the formation of the earth.

Bernardine Gomesius *, about two hundred years ago, published an ingenious

* Gomes. de Sale, l. i. c. 24.

genious treatiſe upon ſalt: in this treatiſe, after reciting, and refuting, the opinions of Empedocles, Anaxagoras, and Ariſtotle, upon the ſubject in queſtion, he propoſes his own; wherein he maintains that the ſea was originally created in the ſame ſtate in which we at preſent find it, and impregnated from the very firſt with the ſalt which it contains. Though this hypotheſis may be conſidered by ſome, rather as a cutting than any untying of the knot, yet it has been embraced by philoſophers of great eminence *; and it muſt be owned that it may be applied to the ſolution of ſome phænomena with peculiar propriety. Naturaliſts aſſure us, that, though ſome few ſpecies of fiſhes

* Kircher Mun. Sub. L. iii. c. iii.——Nollet. Lec. de Phyſ. Tom. IV. p. 62.

fishes thrive in fresh water, and some others live alternately in fresh water and salt, yet by far the greatest number cannot exist out of the sea: now whether we suppose the sea to have become salt from the influx of rivers, or from the gradual solution of beds of rock salt, or from the combined influence of both these causes, it must for some years have remained so exceedingly fresh, that it will not be an easy matter to account for the continuation of the existence of the numberless species of fishes, which cannot live in fresh water. This difficulty is not removed by supposing that fishes do not imbibe any part of the sea's saltness with their food, and attributing the efficacy of sea water in preserving life, to the superior weight with which it compresses the organs

of

of refpiration, for this fuperior weight is as much an effect of the falt diffolved in it, as the faline tafte itfelf. The faltnefs of the *Cafpian* fea, of the lakes of *Mexico*, and *Titicaca*, and of other large collections of waters, which have no effluent rivers, nor vifible communication with the fea, may be as fuccefsfully explained upon this hypothefis,—that the fea was at the creation impregnated with falt —as upon either of the preceding.

Befides the opinions, concerning the caufe of the faline impregnation of the fea, which have been here mentioned, there is another, which future ages will, probably, fee lefs queftionable reafons to adopt than we do: I mean that which maintains —that fea falt is conftantly and abundantly

dantly generated, both on the ſurface of the earth, and in the boſom of the ocean.

But how ineffectual ſoever our attempts may be to explain the cauſe of the ſaltneſs of the ſea; yet one might have hoped, that in this age of philoſophy and curious navigation, the degree of its ſaltneſs in every latitude, and every ſeaſon of the year, would have been aſcertained by accurate experiments. The acquiring knowledge by experiments, is a ſlow and laborious method, but it is, at the ſame time, a method within our reach: whilſt the theoretical inveſtigation of the proximate cauſe of any natural phænomenon often ſurpaſſes, and that of its ultimate cauſe always ſurpaſſes the apprehenſion of the human intellect.

Some

Some experiments tending to the elucidation of this point, reſpecting the ſameneſs or diverſity of the ſaltneſs of the ſea in different places, were made in the courſe of the voyage towards the North Pole, in 1773. We learn from theſe experiments, that the ſea water at the *Nore* contained not quite $\frac{1}{36}$ of ſalt; at the back of *Yarmouth* ſands not quite $\frac{1}{32}$; off *Flamborough Head* rather more than $\frac{1}{29}$; off *Shetland* rather leſs than $\frac{1}{29}$; latitude 74 at ſea $\frac{1}{29}$; latitude 78 leſs than $\frac{1}{28}$; latitude 80, near the ice, not quite $\frac{1}{50}$; latitude 80.30, under the ice, not quite, $\frac{1}{29}$; latitude 68.46, rather more than $\frac{1}{28}$; latitude 65, at ſea, rather leſs than $\frac{1}{28}$*. "Dr. Hales

* Theſe ſeveral quantities are derived from the experiments mentioned in a Voyage towards

Hales got only $\frac{1}{27}$ from water taken up in the *Mediterranean*, and $\frac{1}{29}$ from water taken up at the *Nore*. Dr. Rutty says, he got $\frac{1}{25}$ from water taken up in latitude 65; $\frac{1}{28}$ from water taken up near to *Dublin*; and $\frac{1}{30}$ from water taken up at *Dungarvan*; and Dr. Lucas, that he got $\frac{1}{27}$ from sea water taken up at *Harwich**." The reader will observe that these experiments do not perfectly accord, as to the quantity of salt contained in water taken up at the same place, as at the Nore, and in latitude 65. This is not to be wondered at; the sea water in the same latitude, is not always equally di-

wards the North Pole, 1773, by Conf. John Phipps, now Lord Mulgrave, p. 143.

* Monro on Mineral Waters, Vol. I. p. 195.

diluted by the fresh water which falls from the atmosphere; nor can we be certain, that different persons, in making experiments of this kind, have always used the same degree of heat, in drying the residue which remains after the evaporation of the water; or that they have evaporated the water with the same degree of heat: and yet this circumstance alone may occasion a great disparity in the quantity of the saline matter, separable from a definite weight of sea water. For not to insist upon, what has been before mentioned, the decomposition of a part of the sea salt, which takes place when a solution of it is evaporated with a great heat, it may be observed, that the sea salt in substance is dispersed, when a saturated solution of it is evaporated with even less than a boil-

a boiling heat. This is very clearly ſeen, when a ſmall quantity of a ſolution of ſea ſalt is evaporated to dryneſs in a deep copper veſſel, for the inſide of the veſſel, which can come in contact with nothing but the vapour, is ſpangled with particles of ſalt, which have been carried up with the vapour.

It appears from ſome experiments, formerly made in a voyage from England to *Bombay* in the Eaſt Indies, that the weight of the ſea water was the greateſt, not preciſely at the Equator, but where the ſun was vertical, and conſequently, in ſimilar circumſtances, where the heat was greateſt. The greateſt weight of a definite quantity of ſea water, which was obſerved in ſailing from 28 degrees, north latitude, to the Cape of *Good Hope*,

Hope, which is about $34\frac{1}{2}$ degrees ſouth latitude, in the months of May, June, and July, was at St. Jago iſland, north latitude, 15 degrees; and the leaſt was at Teneriff iſland, north latitude 28. The weights of equal bulks of Thames water, of the ſea water at Teneriff, and St. Jago, were 649—$673\frac{1}{2}$—$780\frac{1}{2}$ grains*; the proportion of which numbers may be nearly thus expreſſed.—Thames water 1000,—Teneriff ſea water 1022;—St. Jago ſea water 1184. By comparing theſe numbers with a Table in the Philoſophical Tranſactions, exhibiting the comparative weight of equal bulks of ſimple water, and of water impregnated with different portions of ſea ſalt, it may be conjectured, that the Teneriff ſea water

* Gentleman's Mag. Vol. XXV. p. 260.

contained about $\frac{1}{31}$ of falt, and the St. Jago water above $\frac{1}{4}$ of its weight of falt, fo that it was nearly, if not fully faturated*.

As it is not every perfon who can make himfelf expert in the ufe of the common means, of eftimating the quantity of falt contained in fea water, I will mention a method of doing it, which is fo eafy and fimple, that every common failor may underftand and practife it; and which, at the fame time, from the trials I have made of it, feems to be as exact a method, as any that has yet been thought of.—Take a clean towel or any

* I formed the table here referred to above 10 years ago; I have reafon to think, that thofe who have leifure and accurate inftruments, might make it more correct, by ufing more precaution than I did in fome particulars, efpecially in what relates to the purity of the [illegible]

any other piece of cloth, dry it well in the ſun or before the fire, then weigh it accurately, and note down its weight; dip it in the ſea water, and, when taken out, wring it a little till it will not drip, when hung up to dry; weigh it in this wet ſtate, then dry it either in the ſun or at the fire, and, when it is perfectly dry, weigh it again. The exceſs of the weight of the wetted cloth above its original weight, is the weight of the ſea water imbibed by the cloth; and the exceſs of the weight of the cloth, after being dried, above its original weight, is the weight of the ſalt retained by the cloth; and by comparing this weight, with the weight of the ſea water imbibed by the cloth, we obtain the proportion of ſalt contained in that ſpecies of ſea water.

Whoever undertakes to ascertain the quantity of salt, contained in sea water, either by this or any other method, would do well to observe the state of the weather, preceding the time when the sea water is taken out of the sea, for the quantity of salt contained in the water near the surface, may be influenced, both by the antecedent moisture, and the antecedent heat of the atmosphere. And this leads to the consideration of a question proposed by *Aristotle**, —Why are the upper parts of the sea salter and warmer than the lower? —Some philosophers admitting the fact, have followed him in attempting to explain it; whilst others have thought themselves authorised by experiment, to deny the truth of the posi-

* Arist. Prob. S. xxiii. 9. 30.

position; and those, perhaps, will argue with the greatest justness, who shall affirm, that it is neither generally to be admitted, nor generally to be rejected, but that the sea in some places, and under certain circumstances, is salter and warmer at the surface, than at any considerable depth beneath it, while in many others the reverse is true. The question consists of two parts, betwixt which, though there, probably, is a connection, yet it is not so necessary a one, as to hinder us from considering each part by itself.

As to the saltness of the sea at different depths, we have different accounts concerning it. There are two methods of estimating the relative quantities of salt contained in

different ſpecimens of ſea water; one conſiſts in weighing equal bulks of them, ſuppoſe a pint or a bottle full of each; for if they have equal weights, it is ſafely enough inferred, that they contain equal quantities of ſalt: the other conſiſts in evaporating a pint, or any other meaſure of ſea water, and weighing the ſalt (which is not evaporable) remaining after the water is wholly diſſipated. Mr. Boyle found, that equal bulks of water taken up in the *Channel* between *France* and *England* at the ſurface, and at the depth of fifteen fathoms, were equally heavy, and thence he concludes, that the ſuperficial water was as ſalt as that at a great depth*.

On

* Boyle's Obſerv. on the Saltneſs of the Sea.

On the other hand, Count Marsilli obtained, by evaporating the water, a thirty-second part only of its weight of salt from water, taken up on the surface of the sea in the gulf of *Lyons*, whilst that taken up at the same time and place from a great depth gave him a twenty-ninth part of its weight of salt; and he thence infers, the greater saltness of the sea at the bottom than at its surface*. In this conclusion he has been supported by experiments made in the gulph of *Bothnia*.

There can be no reason to suspect the accuracy with which any of these experiments was made: in different places the facts will probably be different. The *Rhone* discharges much *fresh* water into the gulf of

Lyons;

* Histoire Phys. de la Mer.

Lyons; this fresh water being lighter than the sea water, will not readily mix itself with it, and for this reason the superficial water will be most diluted by it, and from that circumstance it will contain less salt, in a definite quantity, than the water which is at a greater depth. At Northwich they pump their brine, which is to be boiled into salt, into a very large circular bason, sunk in the ground, and lined with brick, from whence, when its impurities are subsided, it is conveyed to the boiling pans. This bason is exposed to the open air, and in case of a great fall of rain, or snow, they let off the uppermost parts of the water through a wooden tube, which is at other times stopped with a plug, placed

placed upon a level, nearly, with the upper surface of the brine in the bason; what is thus let off is not preserved, but thrown away as useless. This practice proceeds upon the principle we are speaking of, namely, that fresh water is not apt to mix itself, unless it be much agitated with salt water. The gulf of *Bothnia* receives rivers from an immense range of mountains, extending themselves to the east, the north, and the west, far beyond the polar circle; and therefore, as in the gulf of Lyons, its surface may be more diluted with fresh water than its middle or bottom. But in the water of the *English channel*, with which Mr. Boyle made his experiment, the case is very different. This water has

has a communication with the German ocean on one ſide, and with the Atlantic on the other; and, from that circumſtance, it is ſubject to ſuch a conſtant agitation as will occaſion all the freſh water, poured into it by the Thames, Medway, and other rivers of leſs conſequence, to be uniformly diffuſed through all its ſubſtance, ſo as to render it equally ſalt at all depths. The conſtant effect produced on the ſuperficial water of the ſea, by the influx of a large river, is ſomewhat ſimilar to the temporary effect, attending a downfal of rain; the ſuperficial water will be thereby much diluted. It was obſerved in the voyage to Bombay before referred to, that if a quantity of ſea water in dry weather

weighed

weighed 778 grains, an equal quantity immediately after a fall of rain would not weigh above 676 grains, the ſame quantity of Thames water weighing 659 grains. Hence it may be collected, that the weight of a cubic foot of the ſea water before rain exceeded the weight of a cubic foot after rain by 155 ounces.

In the voyage which was made towards the North Pole in 1773, we meet with ſome experiments on this ſubject.

In the open ſea off Shetland, north latitude 60 degrees, equal quantities of water were taken up at the ſurface, and at the depth of ſixty-five fathoms; theſe different waters yielded by evaporation equal quantities of ſalt, namely, $\frac{1}{27}$ of their weight nearly.

On

On another occaſion, in north latitude 65 degrees, ſome water taken up from the ſurface gave nearly $\frac{1}{25}$ of its weight of ſalt, whilſt an equal weight taken up from the depth of 683 fathoms in the ſame place, gave only $\frac{1}{32}$ *.

It is obvious that the firſt of theſe experiments confirms Mr. Boyle's notion of the ſea being equally ſalt at all depths, and that the ſecond is wholly oppoſite, both to his opinion, and that of Count Marſilli, ſo that the queſtion remains ſtill undecided. There is a circumſtance, however, which I will ſubmit to the reader's con-

* In page 143, from which this account is extracted, the latitude is put equal to 75 degrees; but it appears from pages 117 and 137, that the ſhip on the 4th of Sept. when this experiment was made, was in latitude 65.

confideration, whether it may not be fufficient to explain the different refults of the experiments made during the voyage here fpoken of. The experiments which gave equal quantities of falt from equal quantities of water, taken up at the furface, and at the depth of 65 fathoms, were made on the 12th of June; the others, which gave more falt from the fuperficial, than from the deep water, were made on the 4th of September. Now admitting the faltnefs of the fuperficial water, and of water at the depth of 683 fathoms to have been the fame, in the beginning of June, why may not the quantity of water, evaporated from the furface of the fea, during the hot months of July and Auguft, have left the fuperficial water more impreg-

impregnated with salt than the water at a great depth? It is some confirmation of this notion, that the air in June was only six degrees warmer than the water from the depth of 65 fathoms, and that the air in September, when the experiment was made, was above 26 degrees hotter than the water from the depth of 683 fathoms. The rise of fresh springs at the bottom of the sea, in particular places, may be another reason for our accidentally finding the sea salter at its surface than at any great depth below it. However, neither of the reasons here offered in explanation of the phænomenon are wholly to be relied on; for the fresh water which may accidentally be found at the bottom of the sea will rise up till it becomes as

much

much impregnated with ſalt, as the water incumbent over it is, and the water at the ſurface, which is rendered heavier by the ſun's having evaporated ſome of its freſh particles, will probably ſink downwards, and mix itſelf with the water below it, till the whole maſs of water becomes equally heavy, and conſequently equally ſalt. The fact itſelf, of the ſea being in any caſe ſalter at the ſurface than at its bottom, ought to be aſcertained by repeated experiments.

With reſpect to the temperature of the ſea at different depths, it ſeems reaſonable enough to ſuppoſe, that in ſummer time it will be hotter at the ſurface than at any conſiderable depth below it, and that in winter it will be colder. Suppoſe a

ciſtern, twelve feet in depth, to be filled with ſpring water, of 48 degrees warmth, to the height of eleven feet; then if we fill up the ciſtern to its top, by gently pouring water heated to 100 degrees upon the ſurface of the ſpring water, it may readily be underſtood, that the heat of this water will not be inſtantaneouſly communicated through the whole maſs of water in the ciſtern, but that the water will decreaſe in heat from the ſurface to the bottom of the ciſtern. On the other hand, if on the 11 feet of ſpring water heated to 48 degrees, we pour a foot of water heated only to 33 degrees, it may be expected, that the ſpring water which is neareſt to the cold water, will be ſooner cooled by it than that which is at a greater

 diſtance;

diſtance; and on this account the water at the bottom of the ciſtern will be warmer than that in the middle or at the top. It muſt be obſerved, however, that cold water being, bulk for bulk, heavier than hot water, the water which has only 33 degrees of heat will deſcend by its ſuperior weight, into the maſs of water contained in the ciſtern, and thus the water in the ciſtern will be cooled, not only by the bare communication of cold from the upper water, but by the actual mixture of that water with the reſt, ſo that the difference between the heat of the water at the bottom and top, will not be ſo great as it would have been, if the cold water had not mixed itſelf with the reſt. Theſe

ſuppoſitions of hot and cold water incumbent on the ſpring water in the ciſtern, are analogous to the aƈtion of the ſummer and winter atmoſpheres incumbent on the ſurface of the ſea. No perſon, who has bathed in deep ſtanding water in ſummer time, can have failed to obſerve, that the water grew colder and colder, according to the depth to which he deſcended. I have frequently obſerved, that the ſurface of a pool of water of two feet in depth has, in a ſunny day, even in winter, been five degrees hotter than the water at its bottom.

Mr. *Wales* deſcribes the inſtrument he made uſe of for trying the temperature of the ſea at different depths, in the following terms:

" The apparatus for trying the heat of the ſea water at different depths, conſiſted of a ſquare wooden tube, of about 18 inches long, and 3 inches ſquare externally. It was fitted with a valve at the bottom, and another at the top, and had a contrivance for ſuſpending the thermometer exactly in the middle of it. When it was uſed, it was faſtened to the deep-ſea line, juſt above the lead, ſo that all the way as it deſcended the water had a free paſſage through it, by means of the valves which were then both open; but the inſtant it began to be drawn up, both the valves cloſed by the preſſure of the water, and of courſe the thermometer was brought up in a body of water, of the ſame tempera-

ture with that it was let down to.*"
With this inſtrument, which is much the ſame with one formerly deſcribed by Mr. Boyle, in his obſervations about the ſaltneſs of the ſea, water was fetched up from different depths, and its temperature accurately noticed, in different ſeaſons and latitudes.

Auguſt 27, 1772, ſouth latitude 24° 40'. The heat of the air was 72½,—of the water at the ſurface 70,—of water from the depth of 80 fathoms 68 †.

December 27, 1772, ſouth latitude 58° 21'. The heat of the air was 31½,—of the water at the ſurface

* See Aſtronomical Obſervations made in a Voyage towards the South Pole, &c. in 1772, 1773, &c. by W. Wales, Introduction, p. 53.

† Wales' Obſer. p. 206.

face 32,—of water from the depth of 160 fathoms 33½ *.

In the voyage to the high northern latitudes before mentioned, they made use of a bottle to bring up water from the bottom, which is thus described. "The bottle had a coating of wool, three inches thick, which was wrapped up in an oiled skin, and let into a leather purse, and the whole inclosed in a well-pitched canvas bag, firmly tied to the mouth of the bottle, so that not a drop of water could penetrate to its surface. A bit of lead shaped like a cone, with its base downwards, and a cord fixed to its small end, was put into the bottle; and a piece of valve leather, with half a dozen slips of thin bladder were

 strung

* Wales' Obser. p. 208.

ſtrung on the cord, which, when pulled, effectually corked the bottle on the inſide." I have here put down two of the experiments which were made during that voyage.

Auguſt 4, 1773, north latitude 80° 30′. The heat of the air was 32,—of the water at the ſurface 36,—of water fetched up from the depth of 60 fathoms under the ice 39*.

September 4, 1773, north latitude 65°. The heat of the air was $66\frac{1}{2}$,—of the water at the ſurface 55,—of water from the depth of 683 fathoms 40.

It appears from all theſe experiments that, when the atmoſphere was hotter than the ſurface of the ſea, the ſuperficial water was hotter

than

Voyage towards the North Pole, p. 143.

than that at a great depth; and when the atmofphere was colder than the furface of the fea, it is evident that the fuperficial water was fomewhat colder than that at a confiderable diftance below it: and I doubt not that this will generally be the cafe, though fudden changes in the temperature of the atmofphere, which cannot be inftantly communicated to the fea, may occafion particular exceptions.

In the year 1779, feveral experiments were made, with great accuracy, in order to inveftigate the temperature of the lake of *Geneva*, and of other lakes in Switzerland, at different depths; we learn from them, that in winter time there is very little difference between the heat of the

the water at the surface, and at a great depth below it; but that in summer, the superficial water is considerably warmer than that which is at a great distance from the surface. The experiments were made with a thermometer graduated after Reaumer's scale; some of them, reduced to Fahrenheit's scale, are expressed below.

Temperature of the lake of *Geneva* at different depths, in the beginning of February 1779, after a month's uninterrupted frost.

Heat of the open air variable from 37 to 40 degrees.

Water at the surface of the lake,	$42\frac{1}{8}$
Depth 100 feet - - -	$42\frac{1}{6}$
Depth 250 feet - - -	$42\frac{1}{8}$
Depth 950 feet, bottom -	$41\frac{2}{40}$

In

In another part of the lake, open air from 37 to 40.

Surface	- - -	$42\frac{1}{8}$
Depth 350 feet	- -	$42\frac{1}{8}$
Depth 620 feet, bottom	-	$41\frac{27}{16}$

Temperature of the lake of *Neuchâtel*, July 17, 1779.

Air	- - - -	$75\frac{1}{5}$
Surface	- - -	$73\frac{5}{8}$
Depth 225 feet, bottom	-	41*

* The reader will find a great many other experiments of the same nature, in the first volume (the only one yet published) of a very interesting work, intitled, Voyages dans les Alpes, par Horace-Benedict de Saussure, Professor of Philosophy at Geneva.

ESSAY

ESSAY V.

OF FRESH WATER PROCURABLE FROM SEA WATER, BY CONGELATION, AND BY DISTILLATION.

"THE second day we descried a main bank of ice, in the latitude of 60°. We wanting fresh water did sail close to this land of ice, and hoisted out our boat and loader her twice with ice, which made us very good fresh water *."—"About nine of

* Capt. Weymouth's Voy. in 1602. Purchass' Col. B. iv. c. 13.

of the clock in the forenoon we came by a great iſland of ice, and by this iſland we found ſome pieces of ice broken off from the ſaid iſland, and being in great want of freſh water, we hoiſted out our boats of both ſhips, and loaded them twice with ice, which made us very good freſh water *."—"The pieces of ice we took up were hard and ſolid as a rock; the ſalt water which adhered to the ice, was ſo trifling as not to be taſted, and after it had lain on deck a little time, intirely drained off; and the water which the ice yielded was perfectly ſweet and well taſted †."—"In the afternoon we filled our caſks with freſh

* Capt. Weymouth's Voy. in 1602. Purchaſs' Col. B. iv. c. 13.

† Cook's Voy. towards the S. Pole in 1773, Vol. I. p. 37.

fresh water, from the ice, which we found very pure and soft *."

Notwithstanding these testimonies of our most experienced navigators, concerning the fresh water which they procured from the thawing of the ice, they found floating in the sea; yet it might still remain a matter of doubt, whether the ice, from which the water was obtained, had been formed in the sea, and, consequently, whether sea water itself would when frozen yield fresh water. For it might, with some appearance of probability, be said, that the ice had either been formed at the mouths of large fresh-water rivers, and thence by tides or torrents drifted into the sea; or that it had been broken by its

* Phipps' Voy. towards the N. Polo in 1773, p. 60.

its own weight from the immenſe clifts of ice and frozen ſnow, which, in countries where there are few rivers, are found in high latitudes to project a great way into the ſea*; or laſtly, admitting it to be formed in the ſea, it might be urged, that it was formed of freſh water, not of ſalt. *Fotherbye*, in his voyage in 1614, eſteems ſnow the original cauſe of the ice found at ſea, for he obſerved it to be an inch thick upon the ſurface of the ſea; and Captain Cook, from his own obſervations in the South Sea

* *Icebergs* are large bodies of ice filling the vallies between the high mountains.—Large pieces frequently break off from the icebergs, and fall with great noiſe into the water: we obſerved one piece which had floated out into the bay, and grounded in twenty-four fathom; it was fifty feet high above the ſurface of the water. Phipps' Voy. p. 70.

Sea, was disposed to think, that the vast floats of ice he met with in the spring, were formed from the congelation of snow*. Without doubt, the snow which falls upon the surface of the sea, being in a solid state, and, bulk for bulk, lighter than the sea water, will not readily mix itself with it; but may, by a due degree of cold in the atmosphere, be speedily converted into a layer of ice, the upper surface of this first layer of ice being elevated above the surface of the sea, will receive all the fresh water which falls from the atmosphere in the form of snow, sleet, rain, or dew; by the successive congelation of which, the largest fields of ice may at last be formed. Whether the ice found at sea,

* Voy. towards the S. Pole, Vol. II. p. 242.

ſea, be formed according to any one or all of theſe ways, it is evident, that it is produced from an accumulation of congealed freſh water, and that we cannot, from the freſh water procurable from ice thus formed, conclude that the ice of frozen ſea water would yield freſh water.

To a navigator, it is a matter of little conſequence to determine, whence the ice which ſupplies him with freſh water is produced, he is ſure of meeting with more than enough of it for his purpoſe, and he leaves it to the leiſure of philoſophers to decide the queſtion, whether congealed ſea water will, when thawed, yield freſh water. They have decided it by actual experiments, made with every ſuitable attention. Some ſea water was taken up off the *North Foreland*,

it was exposed to a freezing atmosphere, and it afforded an ice perfectly free from any taste of salt.* The specific gravity of the water, produced from the melting of the ice, was somewhat greater than that of distilled rain water, and somewhat less than that of a mixture of rain and snow water taken out of a water tub. The degree of cold, in which the sea water froze, was 28½ of Fahrenheit's thermometer, or 3½ lower than that in which common water freezes*. The degree of cold, however, in which sea water freezes, cannot be ascertained in general, unless it can be shewn, that the sea water, taken up in different latitudes, contains equal quantities of salt, the contrary of which is probably true. And in general,

* Philos. Trans. for 1776, p. 251 & 373.

general, the greater the quantity of ſalt contained in any portion of ſea water, the greater will be the degree of cold neceſſary to freeze it.

We had a ſharp froſt at Cambridge on the 21ſt of laſt December; I filled a thin phial, holding 8 ounces, with ſea water, which contained $\frac{1}{32}$ of its weight of ſalt, and expoſed it ſuſpended from the branch of a tree, during the night of the day before mentioned, to the cold of the atmoſphere. In the morning I found that a part of the water had been frozen: I poured the unfrozen part from the other, and having rinſed the ice in freſh water, ſo as to ſeparate from it the ſalt water which adhered to it, I thawed it before the fire, and found the water which it gave to be wholly free from ſalt.

It

It had been long ago asserted by Macrobius *, that sea water was never frozen, but that the ice found at sea, proceeded from the freezing of the fresh water spread over its surface by the influx of rivers. And in modern times, the opinion, concerning the freezing of sea water, seems to have been admitted with great caution, by our most experienced navigators. They were aware, indeed, that the Baltic and other large seas, were frequently frozen quite over, but they appear to have thought that falls of snow laid a sufficient foundation for the production of that event, "without its being at all necessary for the sea water to freeze †."
I cannot conceive that there was any

 great

* Macrob. Sat. L. vii. c. 12.
† Cook's Voy. Vol. II. p. 242.

great occaſion for this cautious mode of expreſſion, ſince it had been obſerved, above a hundred years ago, that not only ſea water, but water containing double the proportion of ſalt commonly found in our ſea water, and more than is contained in the ſea water of any climate, might be frozen by the cold prevailing in our atmoſphere *.

This freezing of ſea water, moreover, was formerly practiſed, and, I believe, is ſtill practiſed in ſeveral parts of the north of Europe, with a view to leſſen the expence and trouble of extracting ſalt from ſea water †. Stahl informs us of a chemiſt, who, near

* Boyle's Works, fol. ed. Vol. II. p. 264.

† Junck. Conſ. Chem. Tab. xviii. ſ. 15. And Wallerii Mineral. French Tranſl. Vol. I. p. 316.

near a century ago, endeavoured to expedite the buſineſs of making ſalt, in Sweden and Livonia, by means of froſt. With this view he propoſed the making large reſervoirs to contain the ſea water, and the pumping the concentrated brine from under the ice into proper veſſels, to be boiled in the ordinary way. He obtained a patent, but a combination of ſalt-boilers ruined his project*.

I cannot ſee why this cuſtom might not be introduced into England with great advantage. A third part at leaſt of ſea water may, by freezing, be converted into ice by the ordinary cold of our winters: this ice, conſiſting entirely of freſh water, may be thrown away as uſeleſs, and the re-

 maining

* Traité des Sels, par M. Stahl. French Tranſ. 1771, p. 143.

maining two thirds, being boiled down, will give all the falt contained in the whole of the fea water; thus there would be a faving at leaft of one third part of the fuel employed in boiling fea water into falt *. When it is faid, that the unfrozen fea water contains, all the falt, this muft be underftood with fome reftriction, fince it is probable, that the frozen part will, upon moft occafions, hold a little falt, but not fo much as is contained

* Briftol and other waters containing earth, are found to depofit their earth, or a great portion of it, by being frozen.—Brownrigg on Salt, p. 76. Some ice, taken from under the furface of the fea in *Hudfon's* Streights, being melted, gave 6 ounces of falt from 40 quarts of water.—It is probable, that it would not have given fo large a proportion of falt, had it been previoufly cleanfed from the adhering fea water. Philof. Tranf. 1740, p. 807.

tained in many ſpring waters, which are reckoned ſufficiently pure. Eight pounds of frozen ſea water, taken up near Calais, left upon evaporation 32 grains of reſiduum, about half of which was ſea ſalt. The ſame quantity of unfrozen ſea water, taken up at the ſame place after the froſt, left by evaporation 1412 grains of reſiduum, ſo that the water, by being frozen, had freed itſelf from 1380 grains of heterogeneous matter *.

The ice found at ſea is of different colours and conſiſtencies, ſome is poliſhed and pellucid, and thought to be freſh water ice; another kind is of a ſpungy texture, and of a pale green colour like vitriol; and it has been affirmed, that this kind of ice is

* Journ. des Scavans Mai, 1769. See alſo Boerh. Chem. Vol. I. p. 721.

is ſalt, and conſiſts of ſalt water frozen *. This is a miſtake, both as to the fact and the reaſon of it; for the vitriol coloured ice, when freed from the ſalt water in which it ſwims, is quite freſh †, and ſea water when frozen, we have ſeen, does not yield a ſalt ice.

We may, perhaps, be leſs ſurpriſed at the particles of water, in which ſea ſalt is diſſolved, ſeparating themſelves from the particles of the ſalt, and coaleſcing together without admitting any junction with ſuch a heavy extraneous body, when we conſider, that during the action of freezing, they refuſe all union even with the air itſelf. Water in its fluid ſtate

* Crantz's Hiſt. of Greenland, B. I. c. ii. ſ. 13.

† Philoſ. Tranſ. for 1770, p. 111.

ſtate is ſaturated with air, but it is in a great meaſure, if not wholly, deprived of it by being frozen; and modern philoſophers have followed the opinion of Ariſtotle*, in attributing the inſalubrity (real or ſuppoſed) of water which has been frozen, to the loſs of its air †. "The water we melted out of the ice (taken up at ſea) was perfectly freſh, and had a purer taſte than any we had on board. If any fault could be found with it, it was that the fixed air was

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* Non ſolo rigore nivalis aqua pernicioſa eſt, ſed ob aliam cauſam quam non pigebit aperire auctore Ariſtotele. Omnis aqua, inquit, habet in ſe aeris tenuiſſimi portionem quæ ſalutaris eſt —nix ergo, quæ nihil aliud eſt quàm aqua in aere denſata, tenuitatem ſui cum denſaretur amiſit, et ideo ex ejus reſolutæ potu diverſa morborum genera viſceribus inſeminantur. Macrob. Sat.

expelled from it, by which means almost every one who used it, was affected with swellings in the glands of the throat. Water melted from snow or ice is known always to have this effect, and the constant use of it in mountainous countries produces those enormous wens which are common among Alpine nations*." If the loss of the water's air be the true cause of the tumid throat, observable among the inhabitants of the Alps, and of the glandular swellings here mentioned, it seems as if a very simple process would free it from this noxious quality, and restore it to its original salubrity. A simple exposure to the air, for a few days, would be sufficient for the purpose; since water, which has been

* Forster's Voy. Vol. I. p. 107.

been deprived of its air, imbibes it afresh very readily, and becomes saturated with it in no great length of time. And this readiness of imbibing air makes a material difference between the water obtained from the simple thawing of snow, and river water, though the river water itself should proceed from melted snow; for being in its course constantly exposed to the air, it will soon regain the air which it had lost by being frozen.

This may not be an improper place to observe, that several physicians have rejected the notion of the use of snow water being the cause of the wens here spoken of, and that upon good grounds. For in *Greenland*, where snow water is commonly used, these unsightly protuberances

are never met with * ; nor did I ever ſee one of them in *Weſtmoreland*, where we have higher mountains, and more ſnow than they have in *Derbyſhire*, in which county they are very common. But what puts the matter beyond doubt is, that theſe wens are common in *Sumatra*, where there is no ſnow during any part of the year †.

The poſſibility of extracting freſh water from ſea water by diſtillation, has been long known; and indeed it ſeems as if it could never have been queſtioned by thoſe, who duly reflected upon the origin of all the freſh water we meet with on the ſurface of the earth. The geography of the globe is yet but imperfectly known;

* Rutty's Synop. p. 42.

† Philoſ. Tranſ. for 1778. p. 165.

known; enough, however, is known of it to convince us that a much larger portion of its ſurface is occupied by ſea than by land. The *Atlantic* Ocean appears at firſt view to be larger than the whole Weſtern Continent, and the area of the reſt of the habitable world, even if we take into conſideration the land recently explored in the ſouthern hemiſphere, ſeems as if it could not equal half that immenſe expanſion of water which conſtitutes the *Indian* and *Pacific* Oceans. Philoſophers have attempted by meaſuring the moſt approved maps, and by other ingenious methods, to aſcertain the exact proportion between the land and ſea; great preciſion cannot reaſonably be expected to accompany this inquiry; but when

we

we learn from one, that the ſea covers near three fourth parts *, and from another, that it covers four fifths † of the ſurface of the globe, we may ſurely reſt ſatisfied of the truth of the general poſition, that there is a much greater extent of ſea than of dry land. This immenſe maſs of ſalt water which ſurrounds the globe, is the great primary ſource from which all freſh water is derived. The vapour which is inceſſantly elevated from thence by the heat of the ſun, the action of the wind, and other

* See Dr. Long's Aſtron. Vol. I. p. 168.

† The ſeas, and unknown parts of the earth (by a meaſurement of the beſt maps) contain 160,522,026 ſquare miles; the inhabited parts 38,990,569; Europe, 4,456,065; Aſia, 10,768,829: Africa, 9,[illegible]64,807; and America, 14,110,874. Ferguſon's Tables, p. 300.

other leſs obvious cauſes, conſiſts, generally ſpeaking, of freſh water, which being diſcharged from the atmoſphere, in the form of dew, rain, hail, or ſnow, conſtitutes ſprings, rivers, and ſtagnant pools. The taſte of ſea water is, we know, not only ſalt but bitter; the *common ſalt*, which occaſions its ſaltneſs, and the *Epſom ſalt*, which occaſions its bitterneſs, can neither of them be raiſed in vapour (in any ſenſible proportion) by the ſame gentle degree of heat with which water may be raiſed; in order, therefore, to obtain freſh water from ſea water, we need only copy the proceſs of nature, and diſtil ſea water with a gentle heat. This method of obtaining freſh water from the diſtillation of ſea water, was practiſed by Sir R.

 Hawkins,

Hawkins, in the reign of Queen Elizabeth:—"Although our freſh water had failed us many days, yet with an invention I had in my ſhip, I eaſily drew out of the water of the ſea a ſufficient quantity of freſh water, to ſuſtain my people, with little expence of fuel; for with four billets, I ſtilled a hogſhead of water, and therewith dreſſed meat for the ſick and whole. The water ſo diſtilled was found to be wholeſome and nouriſhing *."

Since the time of Sir R. Hawkins, a great variety of attempts have been made in our own, and in other countries, to procure freſh water from ſea water; they have in general been little elſe than different modes of diſtillation, but many of the authors

* Purchaſs' Collec. of Voy. B. vii. c. 5.

authors of them, either from an ignorance of the real nature of sea water, or from a design of rendering their process mysterious, have mixed different ingredients with the water either before or after its distillation. The manner of procuring fresh water, by the single distillation of sea water, seems at present to have attained a great degree of perfection, both in *France* and *England*. M. de *Bougainville*, in his Voyage round the World, has borne honourable testimony to the utility of the machine for distilling sea water, which was made public in 1763, by M. *Poissonnier*, its inventor. Lord *Mulgrave*, in his voyage towards the North Pole, in 1773, has done equal justice to the method of obtaining fresh water from the sea

 by

by diſtillation, which was introduced into the Engliſh navy, in the year 1770, by Dr. *Irving*. Whether the invention of M. Poiſſonnier ſuggeſted any hints to Dr. Irving, is beſt known to himſelf; but he has unqueſtionably added ſuch *improvements* to that method (to ſay no more), as ſeem to have juſtly intitled him to the parliamentary reward of five thouſand pounds, which he has obtained. The French are as jealous of the glory of their nation in arts as in arms, and the Engliſh, we truſt, will never be their inferior in either; it is to this exceſs of jealouſy we muſt attribute the acerbity, with which one of the beſt chemiſts of the age ſpeaks of Dr. Irving, as having deceived the Parliament of England, by appropriating to him-

felf the difcovery of M. Poiffonnier *.

In order that the reader may have a clear notion of Dr. Irving's method, let us fuppofe a tea-kettle to be made without a fpout, and with a hole in the lid, in the place of the knob: then the kettle being filled with fea water, the *frefh* vapour which arifes from the fea water as it boils, will iffue out through the hole in the lid; into that hole fit the mouth of a tobacco pipe, letting the ftem have a little inclination downwards, then will the vapour of frefh water take its courfe through the ftem of the tube, and may be collected by fitting a proper veffel to its end. This would be an apt reprefentation of Dr. Irving's contrivance:

* Baumé's Chy. Vol. III. p. 588.

trivance: he has adapted a tin tube, of ſuitable dimenſions, to the lid of the common kettle uſed for boiling the proviſions on board a ſhip; the freſh vapour which ariſes from boiling ſea water in the kettle paſſes through this tube into a hogſhead, which ſerves as a receiver; in order that the vapour may be readily condenſed, the tube is kept cool, by being conſtantly wetted with a mop dipped in a tub of cold ſea water.

It appeared from the teſtimony which was delivered to the Lords of the Admiralty, by many reſpectable officers who were eye witneſſes to an experiment, made on board the *Arrogant*, at Spithead, in January 1771, that "80 gallons of ſea water did, in twenty-five minutes, after being put into the Arrogant's copper,

per, and a fire made, diſtil in the proportion of twenty-five gallons per hour, into freſh water, perfectly well taſted, and of leſs ſpecific gravity than the beſt ſpring water in that neighbourhood;" and the ſaid officers gave it as their opinion, that 500 gallons of freſh water might be diſtilled in the ſpace of 24 hours, with the ſame quantity of fuel in proportion to the time, as is required in the ordinary buſineſs of the ſhip. Every ſhip's kettle is divided into two parts by a partition in the middle, one of theſe parts is only in uſe when peaſe or oatmeal are dreſſed, but water is at the ſame time kept in the other to preſerve its bottom. Dr. Irving has availed himſelf of this circumſtance, and by filling the ſpare part of the copper

with ſea water, and fitting on the lid and tube, he has ſhewn, that 60 gallons of freſh water may be drawn off, during the boiling of either of the abovementioned proviſions, without the uſe of any additional fuel: he recommends alſo the preſerving the water which may be diſtilled from the coppers in which peaſe, oatmeal, or pudding are dreſſing, as both a ſalutary beverage for the ſcorbutic, and the moſt proper kind of water for boiling of ſalt proviſions.

In November, 1771, *Lord Sandwich* ſent me two bottles of the beſt diſtilled water which could be prepared by Dr. Irving from ſea water, deſiring my obſervations upon it. In compliance with his Lordſhip's requeſt, I made the following experi-

ments,

-ments, of which I ſent him an account, without venturing to give the moſt diſtant opinion concerning the ſalubrity or inſalubrity of the water. — Exper. 1. Four ounces of the diſtilled ſea water being evaporated by a ſlow fire, upon a ſilver plate, left a pellicle, which was very ſenſibly ſaline to the taſte, and glutinous to the touch.—2. Four ounces of the conduit water of Trinity college, treated in the ſame manner, left a pellicle, but not quite ſo large, nor ſo manifeſtly ſapid, as that from the diſtilled ſea water.—3. The ſame quantity of common diſtilled water, being evaporated in the ſame way, left no ſenſible pellicle.—4. The ſame quantity of common diſtilled water, impregnated with a ſmall drop of

of ſpirit of ſalt, left no pellicle upon the whole ſurface of the plate, but only a yellowiſh ſpot upon that part of it from which the laſt portion was evaporated; this ſpot was glutinous to the touch, and had a bitter metalline taſte.—5. The ſame quantity of common diſtilled water, impregnated with two grains of ſea ſalt, left a pellicle, ſimilar to that left by the diſtilled ſea water, except that it was ſomewhat whiter, had a leſs piquant taſte, and a leſs glutinous conſiſtency. From the 4th and 5th experiments, compared with the firſt, it may be inferred, that the diſtilled ſea water, which I examined, contained a ſmall portion of ſea ſalt, and alſo a ſmall portion of the acid of ſea ſalt uncombined with any baſis. A very minute

minute portion of sea salt, or of the acid of sea salt, may be discovered in a large quantity of water, by the milkiness which ensues on dropping into a glass full of the water, a drop or two of a saturated solution of silver in the acid of nitre.—6. I dropped a solution of silver in acid of nitre into common distilled water; no milkiness ensued, nor was the transparency of the water changed.—7. Into an equal quantity of the distilled sea water, I dropped an equal number of drops of the solution of silver; the water became very turbid, and a copious white precipitation ensued. These experiments shew, that the distilled sea water is not wholly free from saline particles; but it probably contains them in so small a proportion,

portion, as not to injure its salubrity in any sensible degree.

We may be the more disposed to admit the possibility of distilled sea water containing saline particles, when we reflect upon the smell of the acid of sea salt, which circulates through the houses in which salt is prepared, by boiling either sea water or brine. The vapour which arises from the pans in which salt is boiled, being caught and condensed in proper vessels, and examined by proper tests, gives indications both of sea salt in substance, and of its acid. It is not an easy matter to ascertain the precise degree of heat, in which saline particles begin to accompany the vapour which is raised from solutions of sea salt; it is probably a de-

gree

gree far inferior to that in which water boils: at leaſt we are certain, that ſaline particles are found in rain and ſnow water, both of which are derived from vapours raiſed into the atmoſphere by the action of the ſun upon the ocean.

ESSAY VI.

OF CALCAREOUS EARTH, CRUDE AND CALCINED.

THE word *Calx* has been introduced into the English language from the Latin; it properly denotes the friable earth, to which some sorts of bodies are reduced by fire; the operation by which they are reduced to that ſtate, is called *calcination*, and a very large claſs of bodies, from their being peculiarly ſubject to be converted by fire into a calx, have been deno-

denominated, by various mineralogists, *calcareous* bodies; the calx or powdery earth, procured from calcareous fubftances by calcination, is commonly called *lime*, more philofophically *quicklime.*

Lead, iron, tin, and feveral other mineral fubftances, may refpectively be reduced by fire to the ftate of a calx; but the earths, obtainable from thefe fubftances by calcination, not poffeffing the other general qualities appertaining to the calces of calcareous fubftances, are not called quicklimes, but calces of this or that fubftance from which they are prepared.

In *Cambridgefhire*, and many of the fouthern counties of England, lime is prepared from the calcination of *chalk*, or, as it is here generally called, *clunch*. The kilns are inverted cones

funk

ſunk in the earth, and lined with brick; the baſe of the cone is about ten feet in diameter, and the depth of the kiln is about fourteen feet. One of theſe kilns will burn about 150 buſhels of lime in twenty-four hours; they uſe generally one buſhel of coal for every four buſhels of lime, and in ſummer, when the chalk is dry, they will ſometimes get five buſhels of lime, from the conſumption of one buſhel of coal; but coal being dear, the chalk is ſeldom well burned. In *Wales*, *Weſtmoreland*, *Derbyſhire*, and many other counties, they burn different ſorts of *limeſtone*, ſome of them approaching to the fineneſs of marble. In *Holland*, where they have neither chalk nor limeſtone, they drag fiſh *ſhells* out of the ſea with nets drawn by horſes,

and burn the ſhells into lime. In the iſlands of the ſouthern hemiſphere they burn *coral rocks* into *chenam* or lime; and in ſome parts of *America* they calcine *madrepores*, and other ſpecies of coral for the ſame purpoſe. Lime may alſo be prepared from the calcination of all kinds of *marble*; of various kinds of *ſpar*; of *ſtalactites*, otherwiſe called *dropſtone*, and in Derbyſhire *watricle*; and of ſeveral other ſubſtances which conſiſt of *calcareous earth*, either *pure*, or mixed with *clay* or *ſand*, or other matters in different proportions. In *Cheſhire*, and other countries, where they have no common materials for making of lime, it would be worth while to examine the earths which may be met with upon the ſurface of the ground, or at a little diſtance below it; for

calcareous ſubſtances are not always united into hard compact maſſes, but are ſometimes found in the form of earth, and that of different colours.

Calcareous ſubſtances are in ſome countries calcined with pit coal, in others with the cinder of pit-coal, in others with wood, in others with peat, in others with furze; the kind of fuel ſeems to be of no conſequence, provided the degree of heat be the ſame. Some ſorts, indeed, of pit-coal are apt, eſpecially when uſed in large quantities, to cake together, and thus hindering, in ſome meaſure, the equal diffuſion of the heat, the ſtone remains unburned. In order that the heat may penetrate through every part of the ſubſtance to be calcined, it is uſual to break it into ſmall pieces; but if the calca-

reous ſtone happens to be naturally ſhaken or ſplit into layers, large pieces may be calcined, by placing them ſo that the flame of the fuel may, in aſcending, find its way between the ſeveral layers of which the ſtone conſiſts. In ſome parts of Yorkſhire, they burn pieces of this ſort of ſtone, a foot in thickneſs, and a foot and a half in length, without breaking them; they uſe generally eight dozen of coal to a kiln, and obtain twenty-two dozen of lime, the dozen containing thirty-ſix buſhels.

It is probable, that there is a certain definite degree of heat, to which any particular kind of calcareous ſubſtance ought to be expoſed, in order to its being converted into the beſt poſſible lime. If the heat be too ſmall, the whole of the ſubſtance will not

not be converted into lime ; and on the other hand, it is poſſible, that the heat may be ſo great as to reduce the ſubſtance to a kind of glaſſy *ſcoria* ; and whenever it becomes vitrified, it will loſe the properties of lime. I am aware of what is generally ſaid, that calcareous bodies, when pure, cannot be vitrified with the greateſt degree of heat ; but though the heat of a chemical furnace may not be ſufficient for the purpoſe, yet there is reaſon to believe that a ſuperior degree of heat may effect a kind of vitrification ; certain it is, that the lime-burners are careful not to give too much heat, leſt they ſhould injure the quality of the lime. When the heat has been too violent, they, in many kilns, find ſeveral pieces of limeſtone co-

vered with a glaſſy coat, and ſticking together. I do not take upon me abſolutely to ſay, that this effect is to be aſcribed to a beginning vitrification of the limeſtone; it may either proceed from thence, or it may be accounted for by ſaying, that the aſhes of the fuel adhering every where to the ſurface of the calcareous ſubſtance, have, in particular places, where they happen to be amaſſed in ſufficient quantity, contributed to its vitrification. This vitrification of calcareous earth, when mixed with other ſubſtances, is obvious enough in the iron furnaces, where they are accuſtomed to mix limeſtone with the iron ore, the *ſcoria* or *ſlag* of an iron furnace perfectly reſembling glaſs.

There is a very ſingular experiment, which may be properly mentioned

tioned in this place. Mix well together equal weights of powdered chalk, or other calcareous body, and powdered pipe clay, put the mixture into a crucible*. Any where towards the middle of the crucible, put two solid pieces, one of pure chalk, the other of pure clay, so that they may not be contiguous to each other, but be every where severally surrounded with the mixture of chalk and clay; then by exposing the whole to a strong degree of heat for a sufficient length of time, it will be found that the mixture has been converted into

* Crucibles are round or triangular vessels of different dimensions, wider at the top than at the bottom; they are principally used for the melting of metals, and are made of clay and sand, or of clay and black lead, or of such other materials as can resist the strongest fires without melting.

into glaſs ; and upon breaking the vitrified maſs, we ſhall diſcover the two ſolid pieces of chalk and clay, unvitrified, and unaltered in their figure, though every where ſurrounded with glaſs. Any other ſort of clay would probably anſwer the purpoſe as well as pipe-clay, but I have always made the experiment with that, as being one of the pureſt clays. From this experiment it is certain, that a mixture of calcareous earth and clay is reducible to glaſs, in a degree of heat which is not ſufficient to vitrify either of theſe ſubſtances when pure. The clay, of which bricks and tiles are made, often contains a quantity of calcareous earth, and hence we may underſtand the reaſon why ordinary bricks and tiles are not able to reſiſt a great

degree of heat: a tile covering a cru-
cible is often quite vitrified, whilst
the crucible remains unaltered, the
tile being a mixture of clay and cal-
careous earth, and the crucible being
made of pure clay and sand.

It is well known, that lime is
lighter, bulk for bulk, than the chalk
or stone from which it is made, some
substance therefore or other is dissi-
pated during the calcination; the
nature of this substance will be in-
quired into hereafter, at present our
concern is to ascertain its quantity.
The substances which I converted
into lime, were fine white marble
called statuary marble; Sienna mar-
ble; fine transparent crystallized spar,
of that species which mineralogists
have denominated hexagonal trun-
cated; rhomboidal opaque refracting

spar;

ſpar; rhomboidal tranſparent refracting ſpar; all theſe ſpars from Derbyſhire; a marble, of a blueiſh caſt, called dove-marble; purple-veined marble; Clitheroe limeſtone; Purbeck ſtone; chalk from Cherry Hinton, near Cambridge; Portland ſtone; Ketton ſtone from Rutlandſhire, denominated *hammites*, from its being compoſed of globules reſembling the roes of fiſhes. A common die is a little cube; if we ſuppoſe the length, breadth, and thickneſs of a die, to be reſpectively increaſed, till each of them becomes equal to an inch, foot, yard, or mile, then will the die become a cubic inch, a cubic foot, yard or mile. The weight of a cubic foot of water is found, by experiment, to be preciſely equal to 1000 avoirdupois ounces. Aſſuming then the

weight

weight of a cubic foot of water to be 1000 ounces, by a method, ſufficiently explained in books which treat of Hydroſtatics, I calculated what would be the weight of a cubic foot of each of the calcareous ſubſtances, which I converted into lime.

Weight of a cubic foot of

Water	1000	voirdupois ounces.
Purple-veined marble	2750	
Sienna marble	2729	
Statuary marble	2725	
Cryſtallized ſpar	2701	
Rhomboidal opaque ſpar	2700	
Dove-coloured marble	2694	
Rhomboidal tranſparent ſpar	2693	
Clitheroe limeſtone	2686	
Purbeck ſtone	2680	
Chalk, near Cambridge	2657	
Portland ſtone	2461	
Ketton ſtone	2456	
Medium of the 12 ſorts	2661	

It

It is unneceſſary to trouble the reader with a particular detail of each experiment, in which one or other of theſe ſubſtances was converted into lime; he will judge it ſufficient to be informed of the general method of proceeding, and to be made acquainted with the general reſult. The method conſiſted in ſelecting pure pieces of the ſeveral ſubſtances, and putting ſometimes two, ſometimes three of them into a crucible filled with ſand; care was taken that the pieces neither touched each other nor the ſide of the crucible; the crucible was then expoſed to a very ſtrong fire for four hours: none of the pieces weighed more than an ounce, ſo that the fire to which they were expoſed, it is apprehended, was quite ſuffi-

ſufficient to convert them into perfect quicklimes; they were all dry, and were weighed very accurately before and after calcination, and in the weighing after calcination great care was taken to free them from every particle of ſand, and to weigh them before they were quite cold. The following table comprehends in one view the different reſults of the ſeveral experiments; the firſt column mentions the different ſorts of calcareous ſubſtances with which the experiments were made; the ſecond expreſſes in hundred weights, quarters, and pounds, the quantity of lime which a ton of each reſpective ſubſtance would yield by calcination; theſe numbers were derived, by the rule of proportion, from the ſmall weights* uſed in the experiments;

ments; the third column exhibits the weight of the matter diſſipated from each calcareous ſubſtance during the calcination.

	C.	q.	lb.	C.	q.	lb.
Purple-veined marble	11	1	24	8	2	4
Purbeck ſtone - -	11	1	22	8	2	6
Clitheroe limeſtone -	11	1	17	8	2	11
Dove-coloured marble	11	1	13	8	2	15
Chalk - -	11	1	9	8	2	19
Sienna marble - -	11	1	7	8	2	21
Portland ſtone - -	11	1	4	8	2	24
Ketton ſtone -	11	1	2	8	2	26
Statuary marble -	11	1	1	8	2	27
Rhomboidal tranſp. ſpar	11	1	0	8	3	0
Rhomboidal opaque ſpar	11	0	12	8	3	16
Cryſtallized ſpar -	11	0	1	8	3	27
Med. of lime from a ton	11	1	$4\frac{2}{3}$			
Medium loſs of weight in a ton	8	2	$23\frac{1}{3}$			

Having

Having formed this table from my own experiments, I was willing to ſee what correſpondence it bore with the experiments of others. Authors ſeldom expreſs themſelves on this ſubject with ſufficient preciſion; I have met, however, with ſome experiments, which ſeem to have been made with great accuracy, and I have from them calculated the following table upon the ſame principle as the preceding.

	C.	q.	lb.	C.	q.	lb.
* Courcelles limeſtone	11	2	2	8	1	26
‡ Calcareous earth ſeparated from marle	11	1	23	8	2	5
‖ Calc. earth from marle	11	1	20	8	2	8
† Chalk - -	11	1	9	8	2	19
§ Vienna limeſtone	11	1	0	8	3	0
* Courcelles limeſtone	11	0	24	8	3	4
¶ Swediſh limeſtone	11	0	18	8	3	10
¶ Gothland coral -	11	0	12	8	3	16
¶ Fiſh ſhells - -	11	0	6	8	3	22
* Courcelles limeſtone	11	0	1	8	3	27
¶ Chalk -	11	0	0	9	0	0
§ Vienna limeſtone	10	2	14	9	1	14
Med. of lime from a ton	11	0	$20\frac{1}{12}$			
Medium loſs of weight in a ton	8	3	$7\frac{11}{12}$			

From

* Paris is principally ſupplied with lime from the Courcelles limeſtone,—the three pieces here mentioned were burned in an ordinary lime kiln for 30 hours. Mem. de l'Acad. 1747, p. 62.

From the bare inſpection of theſe tables it is obvious, that calcareous ſubſtances of different kinds and countries, do not differ much from each other in the quantity of lime which a ton, or any other definite weight of them would yield by calcination.

Though I had every reaſon to believe, that the experiments from which I calculated the tables were made with as much accuracy as the nature of the ſubject would admit; yet

‡ Philoſ. Tranſ. 1773, p. 161.

|| Eden. Eſſ. Vol. III. p. 16.

† Dr. Black, to whom we are indebted for our knowledge of the conſtituent parts of calcareous earth. Eden. Eſſ. Vol. II.

§ Prof. Jacquin's Exam. Chem. Doc. Mev. Vienna, 1769.

¶ Wallerius, Swed. Mem. 1760.

yet I thought it would add greatly to their confirmation, if it could be shewn, that the quantity of lime really procured from calcination of a ton of chalk or limestone, was not much different from the medium quantity ascertained by the experiments. I went, therefore, to one of the kilns of this country, where they burn chalk into lime; and I first weighed four bushels of chalk, which had been dried by the heat of a hot summer; the medium weight of the four bushels was 86½ pounds: I then weighed four bushels of the lime, warm from the kiln, the medium weight of which was 66¼ pounds. Calculating, from these numbers, the weight of lime which a ton of chalk would yield, it will be found to amount to 15c. 1q. 7lb.

—This

—This quantity of lime being so different from what I expected, brought a piece of the chalk to my elaboratory. I then weighed it accurately, and found that a month after, though the weather was hot, it had neither gained nor lost weight. I then converted it into lime, and it gave after the rate of 11c. 1q. 19lb. of lime from a ton; or 3c. 3q. 16lb. less than what the same chalk when burned in the kiln would yield. I take this difference to be wholly attributable to the superior degree of heat, with which the chalk in my experiment was burned. It is to be wished that more coal was used in the burning of lime in this country; for if a ton of chalk, when properly burned, ought to weigh only about 11 hundred weight, and it does ordinarily

weigh about 15 hundred weight, it is obvious that the purchaſer has about 4 parts in 15 which are not lime but chalk; and to this cauſe are to be referred the hard lumps, which are found in the lime of this country, when it is ſlacked; theſe lumps being nothing but chalk which is not burned into lime for want of a ſufficient fire; the expence alſo of carrying 4 tons of chalk in every 15 tons of lime, is a circumſtance not to be neglected.

At Pennybridge, in Lancaſhire, they burn a hard limeſtone, a Winchester buſhel of this ſtone weighed 184lb. The ſame meaſure of the lime, when juſt burned, weighed 109lb. Theſe numbers give 11 c. 3 q. 11 lb. of lime from a ton of the ſtone.

The lime burned at Clitheroe, in Lancaſhire, is reckoned to be as good as any in the kingdom, when applied either as a manure or as a cement: a buſhel up heaped of the beſt crude ſtone weighed 147 pounds, an equal meaſure of the ſame ſtone after calcination weighed 71 pounds; from this proportion it follows, that the Clitheroe limeſtone would give only 9 c. 2 q. 17 lb. of lime from a ton of the ſtone,—this concluſion might be rendered more certain if the medium weight of ſeveral buſhels was taken. It may, however, be expected that the Clitheroe limeſtone ſhould loſe more weight than the Cambridgeſhire chalk does, for in burning it they uſe at leaſt twice as much coal, or one meaſure of coal to two of limeſtone. This propor-

tion of coal is a very great one. At Knaresborough, where they burn a kind of limestone formed by petrefaction, they use 1 bushel of coal to 3 of lime.

From what has been said, it must be concluded, that calcareous substances have a very great resemblance to each other, as to the quantity of that matter which is dispersed from equal weights of them during calcination; and here a curious question presents itself, which cannot be easily decided:—Is the difference in the quantity of lime, procurable from equal weights of different calcareous substances, to be accounted for, from the different proportion in which the earth remaining after calcination is united, in the crude substance, with the volatile part dispersed

during

during calcination; or does it proceed from some unavoidable inaccuracy in making the several experiments?—It must be acknowledged, that it is difficult to say whether the bodies are equally dry before they are submitted to calcination, unless we knew the precise degree of force with which they imbibed and retained the humidity of the atmosphere; it is difficult also to give them exactly the same degree of heat during their calcination, and to weigh them whilst they are equally warm; the greatest attention, moreover, cannot always prevent a loss of some part of the substance to be weighed, nor a gain in weight from the accretion of some heterogeneous matter; yet, notwithstanding these, and, perhaps, other sources of error in

making the experiments, I am rather difpofed to think, that the proportion in which the fixed earth is united to the volatile fubftance, is not the fame in all calcareous bodies.

A piece of dry chalk, and the three Derbyfhire fpars were put into the fame crucible, and expofed for four hours to the fame fire; it appeared, from the experiment, that a ton of the chalk would have given 36 pounds more of lime than a ton of the fpar which gave the leaft quantity of lime, and that the fpar which gave the moft lime from a ton, exceeds that which gave the leaft by 27 pounds.

I made another experiment with the fame view. Six different calcareous fubftances, which had been kept in the fame room for a month,

or more, were put into the ſame crucible, and expoſed to a very ſtrong fire for 24 hours. I weighed them all whilſt they were warm, and the quantities of lime which a ton of each would have given, with that degree of heat, are expreſſed in the following table:

	C.	q.	lb.
Chalk - -	11	1	6
Clitheroe limeſtone	11	0	22
Sienna marble -	11	0	8
Statuary marble	10	3	21
Rhom. ſpar -	10	3	2
Cryſtallized ſpar	10	1	26

From this experiment it may be inferred, that the difference between the quantities of lime earth, procurable, under ſimilar circumſtances, from a ton of chalk, and a ton of hard tranſparent cryſtallized ſpar,

is

is 92 pounds, or near $\frac{1}{24}$ of the whole weight.

Whether this difference be greater than what might ariſe from different ſpecimens of the ſame *kind* of calcareous ſubſtance, is more than I dare poſitively affirm. One ſpecimen of the Courcelles limeſtone, we have ſeen, gave after the rate of 11 c. 2 q. 2 lb. from a ton of the crude ſtone; another calcined in the ſame kiln gave only 11 c. 0 q, 1 lb. from a ton, the difference is 57 pounds, or about $\frac{1}{40}$ of the whole weight. Different pieces broken even from the ſame lump of chalk, limeſtone, marble, and almoſt every other calcareous ſubſtance, ſeldom conſiſt of preciſely the ſame materials; this is obviouſly ſeen in buildings and pavements, made either

with

with marble, Ketton, or Portland ſtone; there may generally be obſerved hard knobs, which do not wear away ſo faſt as the other parts of the ſtone; and thoſe who are accuſtomed to ſaw any of theſe ſubſtances are fully ſenſible of this diverſity of ſtructure in the ſame block of ſtone, from the greater difficulty of cutting ſome parts of it than others. I broke the ſame ſmall lump of chalk into four different pieces, and calcined them for different lengths of time, with a view of ſeeing whether there was not ſome regular proportion with reſpect to the time according to which the quantity of lime procurable from chalk would vary. I broke alſo the ſame lump of Clitheroe limeſtone into four ſmall pieces, and calcined

them

them for different lengths of time with the fame intention; the refult of the experiments is expreffed in the annexed table.

	Lime from a ton of		
Chalk calcined 4 hours	11	1	21
7 hours	11	2	18
10 hours	11	2	14
24 hours	11	1	6
Clitheroe limeftone calc. 4 hours	11	1	17
7 hours	11	0	1
10 hours	11	1	9
24 hours	11	0	22

The reader will perceive that thefe experiments did not anfwer my intention in making them, fince there does not appear to be any regular decreafe of lime with the increafe of the time of calcination; but they probably point out to us a difference

in

in the compoſition of the different ſpecimens; and, indeed, in the chalk which was burned for 7, as well as in that which was burned for 10 hours, I could diſcern, after calcination, ſome ſmall ſpecks of iron which were wholly inviſible before calcination.

Mr. Whitehurſt * has favoured the world with ſome very intereſting obſervations concerning the *ſtrata* in Derbyſhire; the following is his account of their reſpective thickneſſes, and of the order in which they ſucceed one another; No. 1. denoting the uppermoſt *ſtratum*.

* See his Appendix to the Inquiry into the State of the Earth.

1. Grit	-	120 yards
2. Shale	-	120
3. Limeftone		50
4. Toadftone		60
5. Limeftone		50
6. Toadftone		46
7. Limeftone		60
8. Toadftone		22
9. Limeftone not cut through.		

These feveral ftrata of limeftone, are each of them divided into layers, which have very different appearances. Thus No. 3. which is 50 yards in thicknefs, may be confidered as confifting of five diftinct layers. The 1ft layer, which is contiguous to the fhale, is the black Derbyfhire marble; the fecond is called by the miners, fnail horn marble, from its abounding with fcrew-ftones, and fifh fhells; the 3d is a compact grey limeftone, with feveral large cryftalline fpecks in

in it, but with few ſhells; the 4th has rather leſs ſpecks, and is whiter than the 3d; the 5th layer, which lies immediately over the toadſtone, is likewiſe a grey limeſtone. I examined the relative weights of the black marble, and of the ſecond, third and fourth layers of the ſtratum, No. 3. with great attention, and alſo the quantities of lime which a ton of each would yield; the ſeveral ſpecimens were calcined in the ſame crucible, for the ſame length of time.

Weight of a cubic foot of the crude ſtone.			Weight of lime from a ton.		
		Ounces.	C.	q.	lb.
Layer 1.	-	2690	11	2	7
2.	-	2685	11	1	7
3.	-	2640	11	0	15
4.	-	2650	11	1	4
Medium		2666	11	1	8¼

It

It appears from these experiments, that these 4 layers of the same stratum of limestone, do not lie in the earth according to their weights, the uppermost layer being the heaviest, and the third layer being lighter than that either immediately above or below it. The quantity of lime, which a ton of each would yield, seems to have some dependence on their weights; the heaviest layer yielding the most, and the lightest layer yielding the least lime from the same weight of stone *.

I have

* This observation is not true, I think, concerning calcareous substances in general, for a piece of Derbyshire watricle, which was 30 ounces in a cubic foot heavier than the Derbyshire black marble, being calcined in the same crucible with the marble, gave only 11 c. 0 q. 11 lb. of lime, which is 52 pounds in a ton less than the marble gave.

I have now given an account of 12 experiments made by other authors, and of 32 made by myſelf, on calcareous ſubſtances of different kinds and countries, the medium quantity of lime procurable from a ton of theſe ſubſtances, will be found to amount to 11c. 0q. 25lb. and conſequently the medium loſs of weight will be 8c. 3q. 3lb.

When compact maſſes of any ſort of lime are expoſed to the air, even in a room ſheltered from rain or dew, they ſoon begin to crack, and in no great length of time they fall into a powder, and receive a conſiderable increaſe of weight. The time requiſite for effecting this change, depends much upon the quantity of the ſurface of the lime, which is expoſed to the air, partly, I believe, but I am

not certain, upon the degree of humidity reigning in the atmosphere, and partly upon the nature of the body. A piece of statuary marble was converted into lime on the 10th of Feb. 1779; before its calcination it weighed 540 grains, after calcination and whilst it was yet warm from the fire, it weighed 304 grains; this last quantity was laid upon a piece of clean paper, put into a drawer of my study table, and weighed at different intervals, till it had acquired its utmost increase of weight, which it attained on the 4th of March, it then weighing 515 grains. I weighed this lime for two months afterwards, at different times, but it still weighed the same. Another quantity of lime from statuary marble, was examined in the same way, and it ac-

quired its greateſt increaſe of weight in twenty-two days. It did not ſeem to me, that any other kind of calcareous ſubſtance, when reduced to lime and expoſed to the air, acquired its greateſt increaſe of weight ſo ſpeedily as ſtatuary marble; I make this obſervation with diffidence; for I have neither tried all the ſorts of calcareous ſubſtances, nor any of them under preciſely the ſame circumſtances. There is far greater trouble in making experiments, than thoſe, who have not been accuſtomed to the buſineſs, can readily conceive; many niceties are to be attended to, the leaſt of which being omitted, the concluſion becomes doubtful; the mind, moreover, having once acquired the ſtriking outlines of knowledge, has not always

patience to attempt the filling up the minuter part of the design, especially if its attention can be but accidentally employed upon the subject.

Whoever undertakes to ascertain the time in which lime, prepared from different substances, acquires its greatest increase of weight by exposure to the air, would do well to take equal quantities of the limes, whilst warm from the fire in which they were made, to reduce them immediately to powders equally fine, to expose the powders to the air, in a room free from dust, and to weigh them at stated intervals. Or the experiment may be varied by taking, instead of powders, equal in weight and fineness, solid pieces equal in bulk and surface, suppose a cubic inch of each sort, and I question not

that

but ſome intereſting concluſions, relative to the attractive powers of the different ſubſtances, might be derived from experiments of this ſort carefully and repeatedly made.

The powders into which the limes of different ſubſtances are reſolved by expoſure to the air, have not all the ſame appearance; thoſe of ſtatuary marble, dove marble, Portland ſtone, Ketton ſtone, and, probably, ſeveral other ſorts, are compoſed of little globules viſible to the naked eye; whilſt thoſe of chalk, Sienna marble, and ſpar, have no appearance of globules, nor do they feel ſo harſh and gritty to the touch, as the others do. The whiteſt of all the limes, which I have ever ſeen, is that which may be obtained from the cryſtallized ſpar before mentioned; ſtatuary-marble,

and Portland ſtone, give very white limes, but they are many degrees leſs white, than that from cryſtallized ſpar. The limes from Sienna marble, chalk, rhomboidal ſpar, and Ketton ſtone, have a yellowiſh caſt.

Several experiments were made in order to aſcertain the utmoſt increaſe of weight, which different ſorts of lime can acquire by expoſure to the air. The limes were all looſely folded up in clean paper, laid in the cloſet of a room where there was a conſtant fire, and weighed at different intervals, till they had acquired their greateſt increaſe of weight, which ſome of them did not do in leſs than three quarters of a year. The general reſult of the experiments is expreſſed in the following table; where the firſt column contains the names of

of the ſubſtances, from which the limes were prepared, the ſecond expreſſes the height to which a ton of each ſort of lime would increaſe by expoſure to the air, and the third ſhews the quantity of the increaſe in a ton.

	C. q. lb.			C. q. lb.		
Sienna marble - -	35	0	12	15	0	12
Dove marble - -	35	0	9	15	0	9
Portland ſtone - -	34	3	21	14	3	21
Statuary marble -	34	2	0	14	2	0
Rhomboid. tranſ. ſpar	34	0	16	14	0	16
Purbeck ſtone - -	34	0	8	14	0	3
Cryſtallized ſpar -	33	1	25	13	1	25
Rhomb. opaque ſpar	32	1	21	12	1	21
Clitheroe limeſtone	32	1	15	12	1	15
Ketton ſtone - -	31	3	13	11	3	13
Chalk - - - -	30	2	9	10	2	9

Hence it is evident, that the greateſt increaſe of weight which a ton of

lime, of the ſeveral ſorts here mentioned, would acquire by expoſure to the air, amounts to rather more than three quarters of a ton, and the leaſt amounts to above half a ton. This obſervation is worthy of notice in a practical view; lime is ſometimes ſold by weight, and it is obvious, that the ſeller will be a very conſiderable gainer, if, after having drawn his kiln, he lets his lime remain expoſed to the air for a few days before it is ſold. I have frequently obſerved pieces of new-burned lime, daily increaſing at the rate of one hundred weight per ton, for the firſt five or ſix days. The farmer too, in liming his land, ſhould contrive to carry out his lime as ſoon as poſſible after it is burned, he may otherwiſe for

every

every ton, have the trouble of carrying a ton and a half, or more.

Lime which has once acquired its greateſt increaſe of weight, does not loſe any part of what it has acquired by ſubſequent expoſure to the air, even during the heat of ſummer. Several ſorts of lime, which I apprehended had gained their greateſt increaſe of weight in April and May 1779, were weighed at different times during the ſummer of the ſame year which was frequently very hot, but I did not obſerve that any one of them was diminiſhed in weight by the action of the heat: let the matter, therefore, which is attracted by the lime from the air be what it may, it is a permanent ſubſtance, and not ſubject to evaporation during ſummer. Hence it

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cannot be doubted, that the ſoil upon which lime is ſpread acquires a great increaſe of matter; every ton of lime attracts above half a ton of ſome ſort of matter or other from the air, and adds it to the earth; now this matter would not have become united with the earth without the intervention of lime: but whether any part of the advantage of liming, where the ſoil is bad or ſcanty, may be attributed to this increaſe of the quantity of matter which is derived from the air to the earth, is a queſtion which I have not ſkill enough in agriculture to decide.

I have been told by a gentleman of fortune in Derbyſhire, that he has frequently, with great ſucceſs, ſpread 1000 Wincheſter buſhels of lime

lime upon an acre of ground : let us ſuppoſe a Wincheſter buſhel of Derbyſhire lime to weigh 100 pounds, then will 1000 buſhels weigh 100000 pounds, or above 44 tons; and ſuppoſing one ton of ſuch lime to gain only 14 hundred weight by expoſure to the air, then will the whole acre receive an increaſe of ſoil, from the lime which is ſpread upon it, equal to above 30 tons in weight beyond the weight of the lime.

Having eſtimated the loſs of weight ſuſtained by different calcareous ſubſtances during their calcination, and alſo the gain of weight which the limes procured from theſe ſubſtances acquire by expoſure to the air, it is natural to inquire whether the gain is equal to the loſs. Upon the 6th of March I converted

into

into lime 204 grains of dove marble; the lime weighed whilst hot, 116 grains; upon the 5th of the following November the lime weighed 203½ grains. This lime was frequently weighed from March to November, and if it should be supposed that half a grain was insensibly lost by frequent weighing, then we must conclude that this kind of lime gains by exposure to the air, just as much as the marble it is prepared from loses by calcination. Upon a repetition of this experiment with another specimen of the dove-marble lime, I found the result to be, as accurately as can be expected, the same. If we make no allowance for any loss of weight by repeated weighings, then the increase of weight by exposure to the air must be esteemed

less

lefs than the lofs of weight by calcination, by about one four hundredth part of the weight of the marble.

Some dry chalk, weighing 120 grains, was reduced by calcination to 68 grains of lime; this quantity of lime became, by expofure to the air, when it had acquired its utmoft increafe of weight, 104 grains; that is, it wanted 16 parts in 120, or between one feventh and one eighth of the original weight of the chalk.

The dove marble and the chalk are the two extremes of all the fubftances I have tried; no kind of lime regained fo much weight as that from dove marble, and none fo little as that from chalk. Philofophy may be well employed in accounting for this diverfity; I am only in-

terefted

terested at present in establishing the fact, which seems not to have been sufficiently understood by chemists of deservedly great eminence. M. Macquer says "quicklime combines with the moisture of the air which it seems capable of attracting, by the moisture thus attracted, the weight of the quicklime is doubled *." M. Baumé weighed some lime very accurately, and though he kept it in a cellar

* Chem. Dict. by M. Macquer, artic. Quicklime in the English translation:—The original of this work is excellent in its kind, and it is greatly improved by the very judicious notes of the translator. In justice to M. Macquer, it ought to be observed, that in the second English edition of his Dictionary, the passage quoted in the text is greatly altered; there is no mention made of the *moisture* of the air, and the quicklime is only said to recover a *great part* of its original weight, by exposure to the air.

a cellar for ſeveral years, yet it never regained the weight of the calcareous earth, from which it had been prepared; there was always a deficiency of more than two ounces in a pound *.

I do not queſtion the veracity of either of theſe gentlemen, or their accuracy in making their experiments; but the properties of the particular limes which they examined ſhould not have been given as characteriſtic properties of limes in general. No lime that I ever tried was doubled in weight by attracting matter (be it moiſture or other matter) from the air, yet if a limeſtone could be found, which is not impoſſible, that loſt half its weight by calcination, a ſpecimen of lime from ſuch a limeſtone

* Chymie par M. Baumé, Vol. I. p. 177.

ſtone might, perhaps, be doubled in its weight. On the other hand, I only met with one ſort of lime, that from chalk, which in its increaſe ſeemed to fall ſo far ſhort of the original weight of the ſubſtance from which it was made, as to want more than two ounces in a pound, or between one ſeventh and one eighth of the whole weight. My experiment in this particular inſtance, ſufficiently coincides with the too general obſervation of M. Baumé.

The chalk or clunch of this country is not a pure calcareous earth, it contains a portion of ſand; and hence, when a definite weight of this chalk lime is expoſed to the air, it cannot acquire as much increaſe of weight, as the ſame quantity of purer lime would do: for the ſand,

which is mixed with the lime, is of a very different nature from the lime, and does not attract any thing from the air. This observation may be extended to different sorts of lime-stone, and it may suggest one reason for the diversity, in the strength of different sorts of lime, when used either in building or in agriculture.

The table in which the increase of weight acquired by different sorts of lime, in consequence of their exposure to the air, is expressed, was made with great accuracy; yet is it not to be considered as universally true, even of the substances there mentioned: for there is great reason to believe, that the quantity of matter, which the same sort of lime can attract from the air, depends very much upon the degree of heat with which

the lime has been burned; there is a certain definite degree of heat requisite to make the lime attract the greatest possible quantity from the air. When the heat is not sufficient to convert the whole of the substance into lime, then that part which is not changed into lime, will not contribute any thing to the increase of the weight of the lime when exposed to the air, inasmuch as it possesses no quality of attracting any thing from the air. And, I believe, the observation is equally true, when the heat has been *more* than sufficient to convert the whole of the substance into lime. It has been before mentioned, that six different calcareous substances were changed into lime, by being exposed to a very fierce fire for 24 hours: this

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experiment was made in November, 1779; I have frequently weighed the limes ſince that time; they have all of them acquired their greateſt increaſe of weight; for on weighing them in January, 1781, I found that they had not gained any increaſe of weight in an interval of three months. The following table expreſſes, in the ſecond column, the increaſe of weight which a ton of theſe ſubſtances would have gained, and the third column expreſſes the increaſe which a ton of the ſame ſubſtances would have gained, had they been only expoſed to the ſame fire for 4 hours.

	C.	q.	lb.	C.	q.	lb.
Sienna marble -	8	1	15	15	0	12
Rhomb. ſpar -	8	1	5	14	0	16
Statuary marble	8	0	0	14	2	0
Chalk - -	7	1	13	10	2	9
Clitheroe limeſtone	6	2	9	12	1	15
Cryſtallized ſpar -	6	0	0	12	1	25

These experiments clearly prove the great utility of burning lime with a definite heat, for the excellency of lime, to whatever purpoſe it be applied, depends, probably, upon its diſpoſition to attract that matter from the air, which it has loſt by calcination; and we ſee that none of the limes, which were burned for 24 hours, attracted ſo much from the air, as thoſe did which had been more moderately burned; the difference is very conſiderable in all the inſtances. Would not a

greater

greater degree of heat have ſtill further deprived lime of its property of attracting matter from the air, and thus have made it approach nearer to the nature of glaſs?

We have ſeen how greatly calcareous ſubſtances are diminiſhed in weight by being calcined,—do they receive any alteration of bulk during that operation? Having propoſed this queſtion to various lime-burners, in different parts of the kingdom, I found ſome were of opinion that the chalk or ſtone ſwelled a little, others that it ſhrunk a little during calcination, and a third ſet thought that it underwent no ſort of alteration: the moſt obvious inference from theſe different accounts ſeems to be, that calcareous ſubſtances do in this particular differ from each other.

 I took

I took a piece of blackiſh marble, four inches in length, half an inch broad, and one quarter of an inch thick, and having placed it in a proper veſſel, and covered it with ſand, it was expoſed to a very fierce fire for three hours; the marble thereby became perfectly white and friable as calcined bones, but I could not obſerve that it had undergone the leaſt change in any of its dimenſions.

I cut a piece of chalk till it was an inch in length, half an inch in breadth, and as much in thickneſs; after it was calcined, its dimenſions were not ſenſibly altered.

A piece of rhomboidal ſpar from Derbyſhire, and a piece of white marble, were ſeverally meaſured

before

before and after calcination, but no difference could be obſerved in the dimenſions of either of them.

I thought the length of a piece of Sienna marble, in one experiment, was diminiſhed about one fiftieth part by calcination, but I was probably miſtaken; for in another piece, above two inches in length, I took, with a pair of compaſſes, the diſtance between two points upon its ſurface before calcination, and found that diſtance preciſely the ſame after calcination.

A piece of Clitheroe limeſtone, which had been calcined for four hours, appeared to be diminiſhed in length one part in twelve; another piece, which had been calcined ten hours, was unaltered in length, and thick-

thickneſs; and ſo was a piece which had been calcined 24 hours.

I took a piece of chalk, which had been dried by the ſun and air, and having ſhaped it into a ſquare, each ſide of which was four inches, the thickneſs being two inches, I put it into a lime-kiln; it was kept there as long as chalk which is burned into lime uſually is; when it came out of the kiln, I compared it with the ſtandards of its ſeveral dimenſions, which had been accurately taken before calcination, and could not diſcover that it had ſuffered the leaſt change either in length, breadth, or thickneſs. This experiment was repeated with wet chalk, but neither was this altered in its dimenſions by calcination. Laſtly, I took a flat piece of chalk, about

one

one fourth of an inch in thickneſs, and calcined it for 24 hours; the length of this chalk was three inches, and it was diminiſhed by calcination one tenth of its length.

The reader is poſſeſſed of all I know from my own experiments upon the ſubject; but I will not conceal from him the opinion of M. Baumé, who eſteems the diminution of the bulk of calcareous ſubſtances during calcination, as one of their moſt diſtinguiſhing properties. He does not, indeed, mention any experiments which he had expreſsly made, with a view of deciding the queſtion, but I cannot ſuppoſe, that ſo able a chemiſt would ſpeak from conjecture, when he affirms, that calcareous ſubſtances are ſometimes diminiſhed half their

bulk

bulk during calcination *; and therefore I ſhould apprehend, that the calcareous ſubſtances, which he uſed, were different from any of thoſe on which I made my experiments. Be this as it may, his concluſion is, if at all, certainly not generally to be admitted.

The experiments, by which the nature of any particular ſort of earth is chemically inveſtigated, are principally of two kinds; one conſiſts in obſerving its ſolubility or inſolubility in different menſtruums, the other in noticing

* Le ſecond phénomene que la terre calcaire préſente après ſa calcination, eſt ſa diminution de volume——la retraite de ces parties, pendant leur calcination, eſt quelquefois ſi grande, qu'elle va jusqu'à la *moitié* de leur volume. Chym. par M. Baumé, Vol. I. p. 182.

noticing the changes produced in it by the action of various degrees of heat. We may form a general idea of the operation of fire upon calcareous ſubſtances, from the experiments which have been before relat-ed; I did not ſpare either time or labour, nor was I ſenſible of any want of care in making them; yet I cannot help apprehending, that a numerous repetition of ſimilar experiments might lead to ſome general concluſions, which have eſcaped my obſervation. The following experiments can hardly fail of being acceptable to the reader, as they tend greatly to corroborate what has already been inferred concerning the nature of calcareous earths. We have concluded, that twenty hundred weight, or a ton of any calcareous ſubſtance, conſiſts

of

of between eight and nine hundred weight of ſome matter or other, which is diſſipated during calcination, and of between eleven and twelve hundred weight of earth, which cannot be diſſipated in that degree of heat: now if it can be ſhewn, by a way wholly different from that of calcination, that a ton of any calcareous body does really conſiſt of about twelve hundred weight of earth, and of about eight hundred weight of a volatile ſubſtance, we cannot entertain any further doubt concerning the proportion of the conſtituent parts of calcareous ſubſtances.

If the reader has not been accuſtomed to the making of chemical experiments, and yet ſhould be deſirous of aſcertaining, from his own obſervation, the truth of ſuch as I am going

going to mention, he may do it at a very eaſy rate; he need only procure from his apothecary, a few ounces of the acid of ſea ſalt, and a Florence flaſk, and he will be furniſhed with the main part of the apparatus.

I took a Florence flaſk, and pour-ed into it a ſmall portion of the acid of ſea ſalt diluted with water; the flaſk and its contents were then weigh-ed in a pair of ſcales, which turned with a quarter of a grain; the weight was noted down. I then dropped into the acid, by a very little at a time, 20 grains of a calcareous ſub-ſtance, and ſtopping gently the top of the flaſk with my finger, till the whole was diſſolved, the flaſk was weighed again. Now it is obvious, that if nothing had eſcaped during the ſolution, the weight of the flaſk

and

and its contents, after the ſolution of the calcareous ſubſtance, would have exceeded its weight before ſolution by 20 grains. There was, however, a very conſiderable loſs of weight, in all the ſubſtances which I tried. If inſtead of 20 grains, a ton, or 20 hundred weight of each ſubſtance, had been diſſolved, and no notice had been taken of any weight, leſs than $\frac{1}{4}$ of an hundred weight, the weight of the earth, or other matter remaining in the bottle after ſolution, would have been expreſſed by the ſecond column of the following table, and the weight of the matter loſt during ſolution by the third.

	C.	q.	lb.	C.	q.	lb.
Namure black marble —	13	3	0	6	1	0
Clitheroe limestone —	13	1	0	6	3	0
Chalk —	12	3	0	7	1	0
Ketton stone —	12	3	0	7	1	0
Portland stone —	12	1	0	7	3	0
Purbeck stone —	12	1	0	7	3	0
Mother of pearl —	12	2	0	7	2	0
Dove marble —	12	0	0	8	0	0
Blue-veined marble -	12	0	0	8	0	0
Purple-veined marble -	12	0	0	8	0	0
Statuary marble —	12	0	0	8	0	0
Rhomboidal spar —	12	0	0	8	0	0
Cryſtallized ſpar * —	12	0	0	8	0	0

The

* Six out of the thirteen ſubſtances here examined, loſt 8 parts in 20 during their ſolution, which is the very proportion aſſigned by Dr. Black, in his moſt ingenious Eſſay (Edin. Eſſ. Vol. II. page 104), for the loſs ſuſtained by chalk; it will appear, however, from what follows, that pure calcareous ſubſtances probably loſe 9 parts in 20 of their weight, by being diſſolved in an acid.

The Namure black marble and the Clitheroe limeftone threw up an oily fcum during folution, and left a large portion of black fediment, which probably was iron. The chalk had a whitifh fandy fediment, the Ketton ftone a yellowifh one, Portland, and Purbeck ftone a white one, which looked like particles of fand, and was gritty between the teeth; mother of pearl left feveral foft infoluble flakes floating on the top of the acid: the other bodies either gave no fediments, or very minute ones.

When I firft began making thefe experiments, I was accuftomed to weigh the flafk as foon as the folution was ended, and this led me into an error in eftimating the quantity loft during folution; for, upon further trial, I always found, that the

weight

weight of the flaſk and its contents, taken, as accurately as poſſible, as ſoon as the ſolution was finiſhed, was diminiſhed very ſenſibly in the ſpace of three or four hours. I was at firſt inclined to attribute this diminution to the evaporation of a part of the fluid; but the true cauſe is this, the weight of the air remaining in the flaſk after ſolution, is greater than the weight of an equal bulk of atmoſpherical air. This is eaſily proved, either by ſucking through a pipe the air contained in the flaſk, or blowing it out with a pair of bellows, ſo that the flaſk may be filled with common air; for the flaſk will then be found to weigh leſs than it did before. Sucking out the air is a troubleſome operation, for the air has a diſagreeable taſte in the mouth,

and if ſuffered to paſs into the lungs, might be noxious. This diſagreeable taſte is not to be attributed to any ſubtle particles of the acid, which may be ſuppoſed to float in the inſide of the flaſk, but to the air contained in it; for after the air has been thoroughly exhauſted, ſo that the flaſk becomes full of only common air, no further taſte is perceived.

I took a Florence flaſk, which would hold 26 ounces troy of water; into this flaſk I poured a two-ounce meaſure of the acid of ſea ſalt, and diſſolved ſlowly in the acid a quantity of the pureſt calcareous ſpar, the bottle was weighed as ſoon as the ſolution was ended: I then permitted it to ſtand quiet for two hours, and at the expiration of that time, I blew into it with a pair of bellows, till

the air became taſteleſs; the bottle was then weighed, and it had loſt 7 grains. The weight of common air filling a flaſk, holding 24 ounces of water, is about 14 grains; the weight of the ſame quantity of the kind of air which filled the flaſk, immediately after the ſolution of the calcareous ſubſtance, was 7 grains more, or 21 grains; hence the weight of common air, is to that of the air which filled the flaſk after ſolution, as 14 to 21, or as 1 to $1\frac{1}{2}$. I do not offer this concluſion to the reader as an accurate one, but it is probably not far from the truth.

The circumſtance of the weight of the flaſk being greater, immediately after the ſolution was finiſhed, than it would have been if filled only with common air, was not neglected in

making the experiments mentioned in the table; it was not, however, attended to with ſuch a ſcrupulous exactneſs, as it ought to have been: I made therefore the four following experiments with the greateſt care. The ſeveral ſolutions were ſlowly made, to prevent any loſs of the acid, and the flaſk was not weighed till 20 hours after the ſolution was finiſhed; in which time the air in it had become taſteleſs; nor did the flaſk and its contents ſuffer any further diminution of weight, by a longer expoſure to the air.

120 gr. of white marble loſt by ſolut.	53½ gr.
120 gr. of cryſtal. ſpar loſt by ſolut.	54 —
120 gr. of rhomb. ſpar loſt by ſolut.	54 —
120 gr. of Matlock petrefaction —	54 —

The loſs of weight ſuſtained by the marble during ſolution is ſo nearly

nearly the ſame with that of the other three bodies, that its difference may probably be referred to ſome unavoidable inaccuracy in making the experiment; if this be admitted, we may reaſonably conclude that equal weights of pure calcareous ſubſtances, contain equal quantities of a volatile matter, which is diſperſed during ſolution, and that this volatile matter amounts to 54 parts in 120, or nine hundred weight in a ton, the earth amounting to 11 c.

Since calcareous ſubſtances loſe nearly equal portions of their weight, whether they are calcined in the fire, or diſſolved in acids, it may be preſumed that the matter which is loſt is of the ſame nature in both caſes; this matter is a ſpecies of air. The reader may eaſily convince himſelf of

this by faſtening a flaccid bladder over the mouth of a Florence flaſk, or other veſſel, in which any calca-careous ſubſtance is in the act of ſolution, for the bladder will preſently be blown up, by the matter which iſſues through the neck of the flaſk; and if the neck of the inflated bladder be tied, and the bladder be in that ſtate removed from the flaſk, it will not become flaccid again, but remain blown up, which is a ſufficient proof that it is filled with a ſpecies of air. The air thus ſeparated from calcareous ſubſtances. is very different from common air, in many particulars. We have before ſeen, that the weight of a given bulk of this air, is as much greater than the weight of the ſame bulk of common air, as 21 is greater than 14, or as 3 than

than 2.—The air, it has alſo been remarked, has a ſingular taſte, and common air has no taſte.—This air extinguiſhes flame and animal life, and common air ſupports both.—This air by being ſhaken in contact with water, or otherwiſe mixed with it, impregnates the water with an acidulous taſte, but common air produces no ſuch effect on water.—This air is as much a conſtituent part of the atmoſphere as common air is, for a ton of lime will attract half a ton of this air from the atmoſphere. The particles of matter conſtituting light, are ſuppoſed to be of different magnitudes: are the particles of matter which conſtitute atmoſpherical air of different magnitudes?—Does the ſmell of a room newly plaſtered, proceed from particles of matter

 emitted

emitted by the plaſter, or from the air of the room having undergone a decompoſition, in conſequence of the lime having abſorbed one of its component parts ?

When any calcareous earth has been diſſolved in an acid, it has loſt its air, and is much diminiſhed in weight; it has undergone as great a decompoſition, as if it had been calcined. Calcined calcareous earth or lime, may be reſtored to the ſtate of crude calcareous earth or limeſtone, by expoſure to the air; in conſequence of ſuch an expoſure, it, in a greater or leſs ſpace of time, attracts from the air a part at leaſt of the principle which it had loſt during calcination; but when a calcareous earth has been diſſolved in an acid, and is thereby deprived of its air, it

may

may be wholly reſtored to the ſtate of a crude limeſtone, by an almoſt inſtantaneous proceſs. Suppoſe 20 pennyweights of marble to have been diſſolved in a proper quantity of the acid of ſea ſalt, then will theſe 20 pennyweights have loſt nine parts of their weight; the earth remaining in the acid will only weigh 11 pennyweights. Salt of tartar, pot aſh, and other fixed alkalies contain, in their crude ſtate, a great portion of *fixed air*, of the ſame nature with that which conſtitutes nine parts in 20 of the ſubſtance of marble, and other calcareous bodies. The acid of ſea ſalt, and all other acids, have a ſtronger tendency to unite themſelves with the earthy part (if the expreſſion may be admitted) of fixed alkalies, than to continue united with the

earthy

earthy part of marble, or any other calcareous body. If then into the acid, in which 20 pennyweights of marble have been dissolved, and which really consists of the acid united with 11 pennyweights of earth, we pour a solution of salt of tartar, or pot-ash, the acid will quit the earth of the marble, and unite itself with one of the constituent parts of the alkali; the earth of the marble is by this means set at liberty, and one of the constituent parts of the alkali is also set at liberty, namely, its fixed air; these two will unite together, and by their union, they will form an earth of the same nature as crude limestone, the weight of which is found to be equal to the original weight of the marble, or 20 pennyweights.

From

From the various experiments which have been here faithfully related, without any previous attachment to system, it seems as if we might conclude, that pure calcareous substances are composed of 9 parts in 20 of a volatile substance, which is dispersed, not only during the calcination, but during the solution of the substances in an acid, and of 11 parts in 20 of an earth which is generally known under the name of lime. Several authors of distinguished reputation in Chemistry have thought, that *water* was an essential constituent part of calcareous substances, and from particular instances they have endeavoured to ascertain its quantity in general.— The experiments which I have made do not tend to establish this opinion.

—Into

—Into a new glaſs retort I put two ounces of cryſtalized ſpar, and having fitted a clean receiver of flint glaſs to it, I expoſed it at firſt to a gentle fire, which was encreaſed, by degrees, till it became ſtrong enough to melt the retort; during the whole of the operation I did not obſerve that any water was ſeparated from the ſpar, the tranſparency of the receiver was not ſo much as tarniſhed by a vapour. From this experiment I would conclude, that this ſpecies of calcareous earth does not contain any water which is ſeparable from it in a degree of heat ſufficient to melt glaſs. I took an earthen retort, and put into it ſix ounces of cryſtallized ſpar, and expoſed the retort to a very ſtrong fire till the ſpar had loſt one third of its weight,

there

there was not a drop of water found in the receiver. The retort, when taken out of the fire, appeared to be cracked, ſo that this experiment is not quite ſo convincing as the preceding, though, perhaps, ſufficiently ſo to make us doubt concerning the exiſtence of water as a component part of this kind of ſpar. —I took 720 grains of Derbyſhire watricle, which is the ſubſtance of which the ornamental columns ſeen on chimney pieces are generally formed and diſtilled them with a violent fire in an earthen retort, till they were reduced to 400 grains (that is, till they gave after the rate of 11 c. 0q. 12 lb. of lime from a ton of the watricle), but I did not find any ſenſible portion of water in the receiver; it was indeed clouded with a vapour,

vapour, but this vapour I think arofe from the dampnefs of the retort, or of the fubftance ufed in faftening the receiver to the retort, or from fomething or other unconnected with the watricle.—

ESSAY

ESSAY VII.

OF CLAY, MARLE, AND GYPSEOUS ALABASTER, OR PLASTER-STONE.

ARgillaceous earth, or clay, may be diſtinguiſhed from every other ſort of earth, by its tenacity when wetted with water, and by its growing hard when expoſed to the fire. We may levigate ſand, chalk, or plaſter-ſtone into very fine powder, but theſe powders when kneaded with water, will not form a tenacious

cious ductile mafs, capable of being moulded and turned at the pottery wheel, or of being hardened in the fire like clay. Even clay itfelf lofes its tenacity by being baked in a gentle fire: a potter or a pipe-maker will in vain attempt to fubftitute the powder of potfherds, or of broken pipes, in the place of clay; thefe powders may be ferviceable on fome occafions, when mixed with clay, but they cannot, on any, fupercede its ufe*.

The whiteft clays are efteemed the pureft, but even thefe, befide other impurities, generally contain a very con-

* In the Mem. de l'Acad. des Scien. de Pruffe, 1749, there are fome experiments tending to prove, that the tenacity of clay is owing to fome inflammable matter which is mixed with it, and which is eafily confumed in the fire.

confiderable portion of fine fand. I took 16 ounces of the fineft pipe clay from Dorfetfhire, and by repeatedly washing it in large quantities of water, and pouring off the turbid water, I collected a fandy fediment, amounting, when well dried, to three ounces. I have no doubt that this clay contained a much greater proportion of fand, than what I had been able to collect; for the white particles which had been fufpended in the water, certainly confifted in part of a fand of a finer grain, than what had fettled to the bottom, for they were very fenfibly gritty between the teeth. It may eafily be conceived, that in wafhing clays, the fineft part of the fand contained in them will remain fufpended in the water, and that on this account, the

sediment collected at the bottom of the vessel, in which the operation is performed, will not give the true proportion of the sand which enters into their composition. In confirmation of this idea, we have been instructed by the experiments of a very able chemist, to consider fine white clays, as consisting of about 3 parts in 8 of true argillaceous earth, and of about 5 parts in 8 of sand, or earth, resembling powdered flints *. All sorts of earthen wares, from the coarsest pots to the finest pieces of either Asiatic or European porcelane, consist either wholly or principally

* M. Marggraf's Opusc. Chy. Vol. II. p. 171.—Is it possible, by any artificial or natural comminution of its parts, to reduce the sand found in clay into a true argillaceous earth?

cipally of clay. There are a great many ſorts of clay, which differ from each other in colour, in tenacity, in the degree of contraction which they ſuffer in being burned, in their power of reſiſting the action of fire without being melted, and in many other properties; and hence we need be at no pains to prove, that the properties of earthen wares muſt be very various, according to the properties of the clays from which they are formed; and this variety becomes ſtill greater, when we take into conſideration the ingredients which are purpoſely mixed with the natural clays.

The *flint* or *white-ſtone* ware is made in Staffordſhire, and other places, in the following manner.—Tobacco-pipe clay, which they have

 from

from Dorſetſhire, is beat much in water; by this proceſs the finer parts of the clay remain ſuſpended in the water, whilſt the coarſer ſand and other impurities fall to the bottom. The thick liquid, conſiſting of water and the finer parts of the clay, is further purified by being paſſed through hair and lawn ſieves of different degrees of fineneſs: the clay is then ſufficiently prepared to be mixed with powdered flint, the other ingredient in the ſtone ware. They uſe annually in Staffordſhire about 5000 tons of flint, which they have from Hull. They have a tradition concerning the firſt introduction of flint into their potteries, which is briefly this:—A Staffordſhire potter, about 80 years ago, in travelling to London, met at an inn upon the road

road with an oſtler, who undertook to cure a diſorder in his horſe's eye. The oſtler took a flint-ſtone, and having calcined it for a ſufficient length of time in a hot fire, it became very white; he pounded it into a fine powder, and blew ſome of it into the eye of the animal: the potter took the hint, conceiving that as flints could be calcined and pounded into a fine white powder, they might be uſed in conjunction with clay, to make a whiter ware than the clay would do alone. He amaſſed large quantities of flints, burned and pounded them in ſecret, and found the event anſwerable to his expectation. The diſcovery ſoon became general, and many lives were loſt from the powder of the flint being inhaled by the men employed

in pounding it: horſes were afterwards uſed for the ſame purpoſe, and for ſome time paſt they have been accuſtomed to grind their flint *. If the flints are pounded, or ground by inſtruments of iron, the powder is not ſo good as it ought to be, for the particles of the metal, which are abraded during the operation, being mixed with the powder, give the ware when burned, a bad colour.

They formerly were accuſtomed to grind their flints with *Moorſtone*, or *Granite*; but of late years a large bed of *Chert* (a ſpecies of flint) has been

* I ſuſpect the date aſſigned by this tradition to the potter's diſcovery, for the *grinding* of flints is incidentally mentioned as practiſed at *Broſely* in the year 1697.—Phil. Tranſ. No. 228

been discovered near *Bakewell* in *Derbyshire*, and the Staffordshire and Yorkshire potters prefer it to Moorstone for grinding their flints: it is very hard, and being itself of the nature of flint, the parts of it which are worn off and mixed with the flints in grinding, do not vitiate the quality of the flint powder. It is sold at the quarries for 8s. a ton, of which the *Duke of Rutland*, as lord of the soil, has 5s. and the workmen the other 3s. for raising it. It is reckoned that they annually raise between four and five hundred tons, besides the smaller pieces, which are thrown by as refuse; but which might be calcined upon the spot instead of flint, and being ground there, might answer the purpose of ground flint; though as coals are

comparatively dear at *Bakewell*, and as there is no navigation from thence into Staffordſhire, I am not certain whether the ground *Chert* could be afforded to the potters at an eaſier rate than they can prepare their flint. However, *Chert* is very commonly to be met with in other parts as well as at Bakewell, though not, perhaps, in ſuch large quantities, and therefore the hint of uſing calcined Chert, as a ſubſtitute for calcined flint, may be of ſervice to thoſe who are better ſituated with reſpect to fuel and water carriage, than they are at Bakewell.

When the flints have been properly calcined and ground, they are ſifted in water till the water is, as near as may be, of the ſame thickneſs as that in which the clay is ſuſ-

pended;

pended; then the liquid clay and flints are mixed together in various proportions, for various wares, and left to ſet; the mixture is then dried in a kiln, and being afterwards beaten to a proper temper, it becomes fit for being formed at the wheel, into diſhes, plates, bowls, &c. When this ware is to be put into the furnace to be baked, the ſeveral pieces of it are placed in caſes, made of clay, called *Seggars*, which are piled upon one another, in the dome of the furnace; a fire is then lighted, and when the ware is brought to a proper temper, which happens in about 48 hours, it is glazed by common ſalt. The ſalt is thrown into the furnace (through holes in the upper part of it), by the heat of which it is inſtantly converted into a thick

a thick vapour, which circulating through the furnace, enters every Seggar through holes made in its ſide (the top being covered, to prevent the ſalt from falling upon the ware), and attaching itſelf to the ſurface of the ware, it forms that vitreous coat upon the ſurface which is called its *glaze*.

This very curious method of glazing earthen ware, by the vapour of common ſalt, was introduced into England from Holland, at leaſt it was introduced from thence into Staffordſhire, about 80 years ago, by two Dutchmen. An old man informed the perſon from whom I had the account, that he remembered, when he was a boy, running with others to help to extinguiſh what from the ſmoke he apprehended

to be a fire in the pottery where the Dutchmen were working, but that their entrance was opposed by the proprietors of the pottery, who were unwilling that the cause of the smoke, which was the common salt they were using in glazing their ware, should be generally known.

The *Yellow* or *Queen's ware*, is made of the same materials as the *flint* ware, but the proportion, in which the materials are mixed, is not the same, nor is the ware glazed in the same way. The flint-ware is generally made of 4 measures of liquid flint, and of 18 of liquid clay; the yellow ware has a greater proportion of clay in it; in some manufactories they mix 20, and in others 24 measures of clay with 4 of flint. These proportions, if estimated by the weight

weight of the materials, would probably give for the flint ware, about 3 hundred weight of clay to 1 hundred weight of flint, and for the yellow ware somewhat more clay. The proportion, however, for both sorts of ware, depends very much upon the nature of the clay, which is very variable even in the same pit: hence they cannot be certain of the exact quantity of flint, which they ought to mix with the clay, till they have made some trial of the quality of the clay by burning a kiln of the ware. If there is too much flint mixed with the clay, the ware, when exposed to the air after burning, is apt to crack; and if there is too little, the ware will not receive the proper glaze from the circulation of the salt vapour. This glaze, even when it is

most

moſt perfect, is in appearance leſs beautiful than the glaze on the yellow ware. This yellow glaze is made by mixing together in water, till it becomes as thick as cream, 112 pounds of white lead, 24 pounds of ground flint, and 6 pounds of ground flint glaſs. Some manufacturers leave out the glaſs, and mix only 80 pounds of white lead with 20 pounds of ground flint, and others doubtleſs obſerve different rules, of which it is very difficult to obtain an account. The ware, before it is glazed, is baked in the fire, by this means it acquires a property of ſtrongly imbibing moiſture (we perceive ſomething of this in the force with which a new pipe ſticks to the lips, though the pipe has received a kind of glaze by being rubbed with bees wax after being

being baked), it is therefore dipped in the liquid glaze and ſuddenly taken out, the glaze is imbibed into its pores, and the ware preſently becomes dry: it is then expoſed a ſecond time to the fire, by which means the glaze, which it had imbibed, is melted, and a thin glaſſy coat is formed upon its ſurface: the colour of this coat is more or leſs yellow, according as a greater or leſs proportion of lead has been uſed. The lead is principally inſtrumental in producing the glaze, as well as in giving it the yellow colour; for lead, of all the ſubſtances hitherto known, has the greateſt power of promoting the vitrification of the ſubſtances with which it is mixed. The flint ſerves to give a conſiſtency to the lead during the time of its vitrifica-

tion,

tion, and to hinder it from becoming too fluid, and running down the fides of the ware, and thereby leaving them unglazed. The yellowifh colour, which lead gives when vitrified with flints, may be wholly changed by very fmall additions of other mineral fubftances; thus, to give one inftance, the beautiful *black glaze*, which is fixed on one fort of the ware made at *Nottingham*, is compofed of 21 parts by weight of white lead, of 5 of powdered flints, and of 3 of an earthy, or metallic mineral called *Manganefe*.

The powder into which calcined flints are ground, is whiter than common fand, and of a finer grain; and hence it conftitutes, when mixed with clay, a fpecies of earthen ware, fuperior to that in which fand is ufed

as

as an ingredient; the coarse *stone ware* made at *Bristol*, is composed of tobacco-pipe clay and sand, and is glazed by the vapour of salt, like the Staffordshire flint ware, but it is far inferior to it in beauty. As our flint ware is superior to the stone ware here mentioned, because it is made of materials, which, though of the same kind, are of a finer quality, than those which enter into the composition of stone ware; so is it inferior to all the sorts of porcelane in whiteness and transparency; because powdered flints and tobacco-pipe clay, are neither of them so white and pure as the clays and flints of which all porcelanes are made. According to this notion, the only difference between porcelanes and many sorts of earthen ware, consists in the fineness

and proportion of the ingredients; and these causes joined to the different degrees of heat employed in baking different porcelanes, are abundantly sufficient to account for all the varieties observable in the grain, colour, hardness, and transparency, of different sorts of china.

We are told that the component parts of oriental porcelane, " are (1) a *vitrescent* stony substance, reduced to an impalpable powder, *Petunse*. (2) An *unvitrifiable* unctuous clay, reduced to an impalpable powder also, *Kaolin*. These are thoroughly mixed, the latter in as small proportion as possible, and then moulded and baked. (3) A varnish composed of the finest particles of a soapy earth, dissolved in water to the consistence of a cream, in which,

when dry, the pieces are dipped before they are baked *." The Chinese *Petunse* differs from powdered flints, in being fusible in a strong degree of heat, whereas flints are not fusible in a fire sufficient for the baking of porcelane, unless they are mixed with some heterogeneous matter; and this property of the *Petunse* probably gives to china, a degree of transparency not observable in our flint ware; for the vitrifiable *Petunse*, when mixed with the unvitrifiable clay, may communicate a degree of vitriousness to the compound.

The moorstone or *granite* found in *Cornwall* is thought to resemble the Chinese *Petunse*; and the *Soap-rock*, which is plentifully met with at the *Land's End*, is esteemed a species of *Kaolin*,

* Campbell's Surv. of Brit. Vol. II. p. 18.

Kaolin, and is much ſought after by the makers of porcelane. The granite is looked upon by mineralogiſts as a vitrifiable ſtone; at leaſt, as to the greateſt part of it*; and there may, probably, be diſcovered other ſtones which poſſeſs the ſame property. The lead mines in Derbyſhire abound in two kinds of ſpar, which are very different from each other in figure (where the figure is diſcernible), in weight, and in the change which they undergo from the action of fire. The figure of one of the kinds of ſpar is that of a *lozenge* or *rhomb*: the figure of the other is that of a *die* or *cube*: a cubic foot of the *rhom-*

 boidal

* —— Expoſé au feu, il s'y vitrifie, à l'exception du *mica*, et du cement qui ſouffrent la même violence du feu ſans en être altéré.— Miner. par M. Val. de Bomare, Vol. I. p.

boidal ſpar weighs 2700 ounces; a cubic foot of the *cubical* ſpar weighs 3219 ounces: the *rhomboidal* ſpar, in being calcined in a ſtrong fire, loſes near 18 parts in 40 of its weight, and is changed into quicklime; the *cubical* ſpar in the ſame degree of heat loſes about 1 part in 40 of its weight, and is not converted into quicklime: the *cubical* ſpar may be melted in a degree of heat, in which the *rhomboidal* ſpar remains unmelted; and from this property, the cubical ſpar might, probably, be uſed with advantage by the porcelane manufacturers. Some mines, as thoſe near *Critch* in *Derbyſhire*, yield no kind of ſpar but the cubical; whilſt others yield only the rhomboidal; and ſome yield both: I have ſeen a narrow crack in a limeſtone rock, coated

coated on one ſide with the cubical, and on the other with the rhomboidal ſpar.

Having fallen into the mention of ſpars, it may juſt be obſerved, that *Blue-John*, which has, of late years, been fabricated into vaſes, and other ornamental figures, is of the ſame quality as the cubical ſpar, with reſpect to its fuſibility in the fire; it loſes, moreover, its colour, and becomes white in a moderate heat: the weight of a cubic foot of the blueſt kind is 3180 ounces, and that of a cubic foot of the leaſt blue is 3140 ounces. This ſubſtance was firſt diſcovered (or more properly ſpeaking, it firſt began to be applied to ſome uſe), about 16 years ago, at one of the oldeſt lead mines in *Derbyſhire*, called the *Odin* mine (probably from

its being dedicated to *Odin*, the great God of the northern nations), at the foot of a high mountain called *Mam Tor* near *Caſtleton*. Spars tinctured with the *amethyſt* colour have been diſcovered in other mines; there is great plenty of what they call the *chocolate* coloured ſpar, in a mine at *Critch* (a few miles from *Matlock*), where I ſaw the laſt year, a piece of oak, which had ſtood long in the water of that mine, tinged with a deep purple colour; but the greateſt quantity of *Blue-John* is ſtill raiſed at *Caſtleton*; the largeſt pieces are ſold for 9 pounds a ton, the middle-ſized for 6 pounds, and the leaſt for fifty ſhillings.—But to return to the conſideration of porcelane.

Several European nations, in particular the *Germans*, the *Engliſh*, the

French,

French, and the *Italians*, have, since the beginning of the present century, applied themselves with great industry and ingenuity, to the making of porcelane, and they have all of them arrived at great perfection in the art; though none of the European porcelanes, unless, perhaps, we except the *Dresden*, can yet be said to equal, both in strength and beauty, the porcelanes which are imported from *China* and *Japan*. The Dresden and the German porcelanes, in general, are as unvitrifiable as the Asiatic; while most of the others which are made in Europe, may be vitrified by a longer continuation of the heat, in which they are baked. The being or the not being convertible into glass in a strong fire, is one of the principal criterions by which

connoiſſeurs judge of the goodneſs of porcelane, that being eſteemed the beſt which is the leaſt fuſible. Porcelane being ſeldom expoſed to a degree of heat, greater than that of boiling water, it ſeems to be an odd method of judging of its worth, by inquiring whether it is capable of ſuſtaining, unaltered in its form, a degree of heat ſufficient to convert many other ſubſtances into glaſs; but probably that ſort of it is the moſt hard, and tough, and beſt capable of bearing the ſudden tranſitions from heat to cold, which is baked with the ſtrongeſt heat; and, if this be true, then there is a good reaſon for eſteeming that china to be the beſt, which is the moſt unfuſible, inaſmuch as it has, probably, undergone a ſtronger fire in being baked

than

than the more fusible kinds could support.

There is some reason for thinking, that the strength of porcelane has some dependence on its weight; for the more closely its parts are compacted together, the more forcibly, other circumstances being the same, will they resist the impulse of a stroke, tending to disunite them. I have estimated the relative weights of most of our English porcelanes; but I forbear mentioning particulars, as I should be sorry to say any thing which might have the most distant tendency to injure any individual; especially as the great price of labour in this country, and, indeed, in all parts of Europe, compared with its price in Asia, must ever render the engaging in a porcelane manufactory

a ha-

a hazardous undertaking whilſt the importation of Aſiatic porcelane is allowed. The beſt mode of encouraging the European manufactories of porcelane, would be the impoſition of a heavy duty on that which is brought from Aſia. It is, I believe, generally acknowledged, that the *yellow ware* is far more brittle than the *flint ware*; the relative weights of a cubic foot of theſe wares and of Eaſt India china, were

Eaſt India china	-	2346	ounces avoir.
Flint ware	- -	2188	
Yellow ware	-	1988	

Now ſuppoſing a plate of the common yellow or Queen's ware (for there are very different ſorts of it) to weigh 12 ounces; then will a plate of the flint ware of exactly the ſame

ſame ſize and thickneſs weigh 13[illegible] ounces; and an equal plate of china will weigh $14\frac{1}{6}$ ounces; and hence we need not wonder at the great fragility of the common yellow ware, when compared either with china or flint ware. The coarſe Briſtol ſtone-ware has nearly the ſame weight as china, a cubic foot of it weighing 2340 ounces.

The preciſe meaning of the term *marle* is not yet fully fixed; it is moſt generally uſed to denote an earthy or ſtony ſubſtance, conſiſting principally of *clay* and *calcareous* earth, and falling into powder by expoſure to the air. There are ſeveral ſolid ſtrata of ſtones, ſuch as the Derbyſhire *ſhale* and *toadſtone*, which moulder into powder by expoſure to the air, and yet they are not eſteemed

marles,

marles, because they do not contain any calcareous earth; there are also limestones which contain portions of clay, and clays which contain portions of limestone, but which not falling into powder by the influence of the air, are not classed amongst the marles: and hence these two properties, of containing calcareous earth, and of falling into powder when exposed to the air, may be esteemed characteristic of marles; and they are, perhaps, the characteristics which are most to be relied on, for as to colour and consistency, marles cannot by them alone be distinguished from several other bodies.

As the use of marle in agriculture, depends in some sort of soils upon the quantity of calcareous earth

which it contains, and in others upon the clay which enters into its compoſition, ſome readers will wiſh to be acquainted with a general method of aſcertaining the exact proportion of clay and calcareous earth, contained in any particular kind of marle.

Take an ounce of the propoſed marle, previouſly reduced into powder, and well dried; pour upon the marle a diluted acid of ſea ſalt; an effervеſcence will enſue; this effervеſcence ariſes from the action of the acid on the calcareous earth, for the acid has no ſuch action on pure clay, nor even on clay and ſand, as may be ſeen by pouring a little of it on pipe-clay; when ſo much acid has been added to the marle that no further effervеſcence is obſerved, we may

may conclude that all the calcareous earth contained in the marle is now diſſolved in the acid; put the whole into a filter; the calcareous earth being diſſolved in the acid will paſs through the filter, whilſt the clay will remain upon the filter: waſh the clay, and the filtering paper, by pouring upon them hot water till they are freed from all ſaline particles; the clay being afterwards dried, as the ounce of marle had been, will ſhew, by its loſs of weight, the quantity of calcareous earth which the marle contained. As to the matter which remains upon the filter, and which has been called clay, it may chance either to be pure clay, or a mixture of clay and ſand; if it is the latter, the quantity of ſand may

may be known by waſhing it and collecting the ſediment.

This method of examining how much calcareous earth is contained in any ſpecies of marle, may be uſefully adopted alſo when the clay or marle is to be applied to the making of brick. For if the quantity of calcareous earth is large, the marle in being burned will rather form lime than brick, or the brick at leaſt will ſoon moulder in the air, in conſequence of the calcareous earth falling into a powder like lime.— The marle dug out of the ſame pit is often very different in its properties, ſome parts of it containing ſo much calcareous earth, that they may with advantage be burned into lime; whilſt other portions of it may be made into good brick. I will illuſtrate

illuſtrate what has been ſaid concerning the analyſis of marle, by an inſtance.

We have a ſtratum of lead-coloured clay, a little beyond Magdalen College, on the road to Ely, which burns to a whitiſh brick: I took four ounces of this clay, moiſt as it was dug out of a pit, ten or twelve feet deep; by being dried on a hot fire-ſhovel till no more vapour appeared to riſe from it, the weight was reduced to three ounces. Theſe three ounces, or 60 pennyweights, were put into a quantity of diluted acid of ſalt, till no more efferveſcence was obſerved, the mixture was filtered, and what remained upon the filter, being dried, weighed 46 pennyweights, the quantity of calcareous earth amounting to 14 parts*

in 60, or near $\frac{1}{4}$ of the weight of the clay when dried. What remained upon the filter was washed in much water; I obtained a sediment amounting to about 1 pennyweight, but it was not a sandy sediment, it resembled an earthy salt, resulting from an union of the acid of vitriol with calcareous earth, which is usually called *Selenites*; there was also separated, by washing, a quantity of greyish earth, which was chiefly iron.

The moulds, used in making bricks from this clay, are 10 inches in length, and 5 in breadth, and the bricks, when burned, usually measure 9 inches in length, and 4$\frac{1}{2}$ in breadth, so that the clay shrinks about 1 inch in 10. But the degree of contraction, which clays undergo

in being burned, is very various, and it does not ſolely depend upon the purity of the clay; for I have been informed by perſons employed in making coarſe earthen ware from ſimple clay, that the ſame clay juſt dug out of the earth, and put into the fire, will contract leſs, than when it has been ſome time expoſed to the influence of the atmoſphere; for froſt more perfectly divides its particles than any artificial proceſs can do: the Chineſe are ſaid to let their clay remain expoſed to the atmoſphere 20 or 30 years, before they apply it to the making of porcelane: and the goodneſs of common tiles, and bricks, is much increaſed, by ſuffering the clay to lie mellowing for a year or two before it is uſed.

The

The clay here ſpoken of, though it does not contain ſo much calcareous earth, as to render it a proper manure for ſtiff, loamy ſoils, yet it might probably be uſed, with great advantage, on thoſe which are light and ſandy; inaſmuch as by its clayey part (for clay is greatly retentive of humidity) it would contribute to keep the ground from being deprived of its moiſture, by the action of the ſun and wind during the height of ſummer. The quantity of moiſture which is imbibed by the leaves of vegetables from the atmoſphere, as well as that which is ſucked in by their roots, has a great dependence on the moiſture of the ground on which they grow; for when the ground is dry, the air incumbent upon it will, comparatively ſpeaking,

 be

be dry alſo, and the vegetables which grow in that dry air, will lack a part of that moiſture which is neceſſary to their well being, for whether *moiſture* be itſelf the *food* of vegetables, or only the *vehicle* of food, it is indiſpenſably neceſſary for the promotion of vegetation*.

From the conſideration of marle we paſs to that of *alabaſter*, which is ſeldom found in beds, except in conjunction with marle. There is ſome confuſion both in the philoſophical and in the common acceptation of the term *alabaſter*; I do not mean merely with reſpect to the colour and tranſparency of the ſubſtance, but with relation to its conſtituent parts. This confuſion may be

* Vegetabilia omnia a liquoribus omnino creſcunt.—Newton.

be greatly removed, by admitting two ſorts of alabaſter, which are eſſentially different from each other, *calcareous* and *gypſeous* alabaſter: to which ſort any particular ſpecimen belongs may be determined by the eaſieſt experiment. Dip a feather in the acid of ſea ſalt, touch the ſpecimen of alabaſter with the wet feather, and if an *efferveſcence* enſues, the alabaſter is *calcareous*, it is of the nature of marble, and may be burned into lime; if no *efferveſcence* enſues, the alabaſter is *gypſeous*, it is of the nature of *Plaſter of Paris*, and very different from every ſort of marble. This ſubſtance is called in the north of England *allplaſter*, being a corruption probably of alabaſter, and it is alſo often called by the Latin appellation *gypſum*, eſpecially by the

 French

French. *Gypſum* was applied by the ancients to the very ſame purpoſes to which it is applied by us; they uſed it in architecture for the making of ceilings, medallions, and cornices; and even the name of the perſon, who firſt invented the method of taking off the impreſſion of a man's face in gypſum, has been preſerved by Pliny*.

There are ſome ſorts of *alabaſter* which differ ſo widely in weight, both from the fineſt kinds of plaſter-ſtone; and of calcareous ſtone, that I know not how they can properly be

* Uſus *gypſi* in albariis, ſigillis ædificiorum, et coronis gratiſſimus. Plin. Hiſt. Nat. L. xxxvi. ſ. 59.—Hominis autem imaginem *gypſo e facie ipſa* primus omnium expreſſit Lyſiſtratus. Id. L. xxxv. ſ. 54. where it is obſerved that the *caſt* was improved by pouring wax into the gypſum mould.

be conſidered as being of the ſame nature with either of them. Mr. Cotes has fixed the weight of a cubic foot of alabaſter at 1875 ounces *, and two other authors have repreſented it as weighing 1872 ounces †. I have tried ſeveral ſpecimens of the fineſt Derbyſhire plaſter-ſtone, and find that a cubic foot of it weighs, at a medium, 2286 ounces; a cubic foot of the Derbyſhire watricle, which is a fine calcareous ſtone, reſembling alabaſter in colour, and tranſparency, weighs 2720 ounces.

Two ſubſtances when combined together in different ways, or in different proportions, may conſtitute a great variety of bodies differing much

* Cotes's Hydros.

† Muſſcheubroek—Wallerius.

much from each other in external appearance, and somewhat, probably, in their internal properties. We have an instance of this in the combination of the acid of vitriol with calcareous earth, for this combination constitutes a great many substances exceedingly different from each other in appearance. I will mention some of the most remarkable. (1) A solid substance not so hard nor so heavy as marble, nor so capable of receiving a fine polish, but consisting of finer particles, and having a greater degree of transparency—*Gypseous alabaster.* (2) A substance composed of larger particles than the preceding, and having a scaly or granulated texture—*Plaster-stone.* (3) A substance whose parts, instead of being flat or granu-

lated,

lated, lie in longitudinal fibres, like a parcel of needles, or a ſkein of thread—*Striated gypſum.* (4) A pellucid ſubſtance conſiſting of a number of tranſparent plates of a lozenge-like form, found in great plenty and perfection at *Shotover-hill*, near Oxford—*Rhomboidal ſelenites.* (5) Some take the *lapis ſpecularis* which the ancients uſed inſtead of glaſs, to have been compoſed, like all the preceding bodies, of the acid of vitriol and calcareous earth; whilſt others look upon it as a ſpecies of *talc*, which differs from plaſter-ſtone in this, that it does not, after being calcined and wetted with water, ſwell and concrete into a hard ſtony ſubſtance. This *lapis ſpecularis* came into uſe at Rome in the age of *Se-*

neca;

neca *; it was ſoon after its introduction applied not only to lighten apartments, but to protect fruit trees from the ſeverity of the weather †; and it is recorded to have been principally by its means, that the Emperor Tiberius was enabled to have cucumbers at his table during almoſt every month in the year ‡. I believe

* Quædam noſtra demum prodiiſſe memoria ſcimus, ut *ſpeculariorum* uſum, perlucent teſta, claram tranſmittentium lucem. Sen. E. p. 90.

† Pallida ne Cilicum timeant pomaria brumam,
Mordeat et tenerum fortior aura nemus:
Hibernis objecta notis *ſpecularia* puros
Admittunt ſoles, et ſine fæce diem.
Mar. L. viii. epig. 14 et 68.

‡ Nihilo minus *ſpecularibus* integi debebunt ut etiam frigoribus ſerenis diebus tuto producantur ad ſolem. Hac ratione fere toto anno Tiberio Cæſari *cucumis* præbebatur. Colum. L. xi. c. 3.

lieve it is ſtill uſed in ſome countries in the place of glaſs, and we certainly know that it was ſo uſed in the time of *Agricola*, for he mentions two churches in Saxony which were lighted by it *.

If the *lapis ſpecularis* was a kind of tranſparent *plaſter-ſtone*, it muſt have been ſubject to one inconvenience, it could not have long ſtood the action of the weather: for *gypſeous alabaſter*, *plaſter-ſtone*, *ſelenites*, and all other combinations of the *acid* of *vitriol* with *calcareous earth*, are ſoluble in water, either wholly or in a great degree. Theſe ſubſtances require, indeed, a greater proportion of water to diſſolve them, than any other ſaline ſubſtances do; but they are, nevertheleſs, ſoluble in water.

I took

* Agric. de Natura Foſ. L. v. p. 257.

I took ſome very white plaſter-ſtone, and pounded it into a fine powder; 1 pennyweight of this powder was put into a pail, containing 10 quarts of water; the powder was entirely diſſolved in it; from hence we learn, that this kind of plaſter-ſtone is wholly ſoluble in water; the water was pump water of 48 degrees of heat. I thought that this quantity of water was perfectly ſaturated with 4 pennyweights, or 96 grains of the powder, and hence it ſeems as if ſpring water, which is uſually of the temperature of 48 degrees, would diſſolve about one fourteen hundredth part of its weight of plaſter-ſtone. There are great beds of plaſter-ſtone in the environs of Paris, and the hardneſs of the well water of that city is thought to ariſe from the

particles of plaſter-ſtone which are diſſolved in it.

Agricola eſteemed the *lapis ſpecularis* to have been a ſpecies of plaſter-ſtone, and in ſpeaking of it he remarks, that though it could bear, without being injured, the heat of ſummer and the cold of winter, yet the largeſt maſſes of it were waſted by the rain*. I tied a lump of plaſter-ſtone, weighing two ounces, to the end of a pair of ſcales, and kept it ſuſpended in the middle of a pail of water for 48 hours, the water having been changed two or three times in the interval; at the end of the

* Res *gypſo* cognata *lapis ſpecularis*—fert calores ſolis et hyemis frigora, ſed imbrium adeo impatiens eſt, ut ſi vel magnæ ejus moles ipſis fuerint expôſitæ corrumpantur. Agric, de Nat. Foſſ. L. v. Ed. Baſ. 1546.

the experiment, it appeared, that the plaſter-ſtone had loſt one thirtieth of its weight.

There are many places in England, where plaſter-ſtone is gotten in great abundance; the principal of thoſe which I have ſeen, are at *Chelaſton*, a ſmall village about four miles ſouth from *Derby*, and at *Beacon-Hill* near *Newark*. They annually raiſe at Chelaſton about 800 tons of plaſter-ſtone, which is ſold upon the ſpot for 5s. a ton. It is chiefly uſed for the making of floors in Derbyſhire, Leiceſterſhire, and Nottinghamſhire: that which has a blueiſh caſt is moſt eſteemed for flooring; the very white pieces are ſold to the potters; to the poliſhers of ſpar, who call it alabaſter (though they get their beſt ſort of alabaſter from Staffordſhire); and

to

to the plasterers. The plaster-stone before it is used, either for floors or ceilings, is calcined; it loses in that operation, from 4 to 6 hundred weight in a ton; the loss, however, in the same kind of stone, depends very much upon the degree of heat with which it is calcined. I calcined, in the same crucible, a piece of Derbyshire watricle, a piece of fine grained plaster-stone, and a piece of the striated kind from Chelaston. The watricle lost after the rate of 8 c. 3 q. 17 lb. in a ton; the plaster-stone lost after the rate of 12 c. 0 q. 13 lb. and the striated kind after that of 10 c. 0 q. 2 lb. in a ton. When the stone is calcined, those parts of it which are exposed to the greatest heat, are sometimes melted, and they frequently acquire a yellowish cast,

and emit a ſulphureous exhalation, and are in both caſes thrown aſide as uſeleſs. The flooring made from the ſtones, which are become ſulphureous by calcination, is apt to riſe in bliſters; this proceeds from the plaſter-ſtone having loſt a portion of the vitriolic acid, which enters into its compoſition, and being thereby changed into a ſpecies of lime. They calcine the ſtone uſually at night, that they may be the better able to obſerve when it becomes red hot, in which ſtate they judge it to have received heat enough. After calcination they reduce it to a powder, by threſhing it with flails, or grinding it in a mill; and when it is become of a due fineneſs, they mix it with a proper quantity of water, and ſpread it to the required thickneſs upon

 reeds,

reeds, where it immediately concretes into a ſolid floor; 30 hundred weight of the crude ſtone will, when calcined, make 20 ſquare yards of flooring of 2½ inches in thickneſs. For preparing the ſtone, and ſhooting the floor, the Derbyſhire maſons charge 9d. a ſquare yard; hence 20 ſquare yards of plaſter flooring, including the price of the ſtone at the pits, will coſt 1l. 2s. 6d.——The additional expence muſt be various, it depending upon the price of the conveyance of the crude ſtone, from the place where it is dug, to the place where it is uſed. Plaſter-ſtone, however, is found in ſo many parts of the kingdom, and the inland navigations are become ſo commodious, that plaſter flooring might be introduced into many countries with a

confiderable faving of expence; a circumftance efpecially to be attended to in the erection of public infirmaries, and houfes of induftry.

They have fawn out of the quarry at Chelafton, fquare blocks of a yard in breadth and thicknefs, and of two yards in length; and blocks of ftill greater dimenfions have been raifed at a place called *Red-hills*, in the county of Nottingham, about four miles from Chelafton. The ftone from the *Red-hills* is not fo good for flooring, as that at Chelafton; it is, however, a very beautiful ftone, *Lord Scarfdale* having gotten from thence thofe fuperb columns which adorn his hall at *Kedlefton*. Thefe columns are made of different blocks, from 2 or 3, to 6 or 8 feet in height, which are fo artfully cemented together, that they

they may be taken for one piece. The blocks are raiſed out of the quarry, by being ſawn to the proper length on each ſide, and to the depth requiſite for the thickneſs of the column, the block ſtill adhering by its lower ſurface, to the quarry, is broken off from thence by being raiſed on each ſide with levers. It is afterwards rounded into the proper cylindric form by the mallet and chiſel, and poliſhed by being rubbed with various kinds of ſtones, then with emery, and laſt of all with putty. If the veins of the ſeparate blocks which are to compoſe the ſhaft of an alabaſter column of the kind we are ſpeaking of, do not happen to ſuit each other; in order to make the juncture leſs diſcernible, and to give a greater appearance

 of

of confiftence to the whole column, fmall pieces are here and there cut out of the feparate blocks, and others of a different colour inferted, and cemented by a mixture of rofin and bees-wax, tinged green, red, brown, yellow, according to the nature of the piece to be inferted.

Alabafter columns, though they are much eafier to be wrought than marble, and when finely polifhed look very well, yet, I apprehend, their polifh muft be injured by a circumftance which does not affect either *marble* or *calcareous alabafter*. The atmofphere is always much charged with humidity, upon the breaking up of a froft, and in other ftates of the weather, fo much water is difcharged from the air, that marble,

wain-

wainſcot, and other ſubſtances upon which it ſettles, are ſaid to ſweat.— Now the water which thus ſettles on a *gypſeous alabaſter* column, will diſſolve part of the ſubſtance of the column, and as ſome parts of the alabaſter are more ſoluble than others, the uniformity of its ſurface will be injured; and the part, moreover, of the alabaſter which has been diſſolved, will, upon the evaporation of the water, either not adhere at all to the column, or it will adhere in ſuch a way, as to render the poliſh leſs gloſſy. But whether this account of the matter be admitted or not, the fact, I believe, of the poliſh of gypſeous alabaſter being injured by moiſt weather, is not to be denied. The alabaſter columns in the Egyptian Hall at *Holkam*, were dug from the

quarries in Staffordſhire, and the late Lord *Leiceſter* was at the trouble of contriving means to keep them dry in moiſt weather, leſt their poliſh ſhould be impaired by the action of the moiſture.

They annually raiſe about 2000 tons of plaſter-ſtone at the pits near Newark; it is ſold on the ſpot at 5s. 6d. and at Gainſborough at 8s. 6d. a ton, from whence it is ſent to London and various other places.

It having been ſaid, that plaſter-ſtone is a ſaline ſubſtance reſulting from an union of the acid of vitriol with a calcareous earth; the reader may expect ſome proof of the aſſertion.——Boil together pot-aſh and plaſter-ſtone, and you will obtain the ſame kind of ſalt, which would ariſe from uniting the acid of vitriol

with pot-aſh; and thence we conclude, that the *acid of vitriol* is one of the component parts of plaſter-ſtone: that *calcareous earth* is the other, is evident from this conſideration, that the earth, which remains after the acid of vitriol has been ſeparated from the plaſter-ſtone, efferveſces with acids, and may be burned into lime.

Having ſaid ſo much concerning gypſeous alabaſter, which is an earthy ſalt reſulting from an union of the *acid of vitriol* with a *calcareous* earth; it may not be improper to add a word or two concerning *alum*, which is an earthy ſalt, compoſed of the *acid of vitriol* and an *argillaceous* earth. The acid of vitriol, when united with any earth, may be ſeparated therefrom by a fixed alkali; and

if we pour into a ſolution of alum any fixed alkali, the earth of alum will be precipitated, and we ſhall obtain a ſalt, of the ſame kind as would reſult from a direct combination of that alkali with the acid of vitriol; and thence it is inferred, that the *acid of vitriol* is one of the component parts of alum: upon examining the earth, which is precipitated by the alkali, it will be found to be very white, and very tenacious, and to be capable of being hardened in the fire; in ſhort, it is one of the pureſt clays in nature: and thence it is concluded that an *argillaceous* earth is the other component part of alum. The conſtituent parts of alum may alſo be proved by its artificial compoſition, for though the vitriolic acid, when poured upon pipe-clay,

does

does not ſeem to act upon it, yet if it be boiled with it, a ſolution of the clay in the acid takes place, and an alum may be obtained by ſlowly evaporating the ſolution.

Being one day engaged in evaporating ſomething or other, from a ſaucer made of the Staffordſhire yellow ware, I was ſurpriſed to ſee a white ſubſtance bubbling through a crack in the ſaucer; upon taſting it I found it to be a ſalt; I collected a ſufficient quantity of it, and when it was diſſolved and cryſtallized, it appeared to be a perfect alum. The fire was a very hot one, and it was made of coal cinders; the ſaucer was placed on the bar of the grate, and the alum, I conceive, was formed from the *ſulphureous acid* of the cinders uniting itſelf with the *clay*, which

enters

enters into the compofition of the yellow ware. I have been informed by a very intelligent perfon, that the vapour which, in fome places, efcapes from the coal-pits which are on fire in Staffordfhire, forms an alum where-ever it meets with an argillaceous earth. This is very conformable to the manner of making alum on the *Solfatara* near Naples, where they place little heaps of *argillaceous* earths, or ftones, over the crevices from which the fulphureous vapour iffues, in order that they may collect a greater quantity of alum *.

In England we make alum from a black flaty fubftance, called *fhale*; this fubftance is a clay, hardened into a ftony confiftence, and fo much im-

* Lett. fur la Miner. par M. Ferber, French Tranf. p. 261.

impregnated with bitumen, that it burns ſomewhat like coal. We have ſeen, that coal emits, when it is in the ſtate of a red-hot cinder, a ſulphureous acid: many other bitumens, probably, in the ſame ſtate emit the ſame acid, and the acid which is emitted from ſhale during its calcination, uniting itſelf to the argillaceous earth of the ſhale, forms alum. About 120 tons of calcined ſhale will make 1 ton of alum. The ſhale, after being calcined, is ſteeped in water, by which means the alum, which is formed during the calcination of the ſhale, is diſſolved; this diſſolved alum undergoes various operations, before it is formed into the alum of the ſhops. The greateſt alum works, and I believe the only ones which now ſubſiſt in the kingdom,

dom, are at *Whitby*; a few years ago there were ſome in Lancaſhire; and alum might be made in many other parts, but Whitby is ſo conveniently ſituated for coal and water carriage, that alum can be there afforded at a cheaper rate than in moſt other places, and it coſts even there 9 or 10l. a ton making.

ESSAY

ESSAY VIII.

OF PIT-COAL.

I Took 96 ounces of *Newcastle* coal, and putting them into an earthen retort, distilled them with a fire gradually augmented till nothing more could be obtained from them. During the distillation there was frequent occasion to give vent to an elastic vapour, which would otherwise have burst the vessels employed in the operation. The weights of the

the liquid found in the receiver, and of the residuum remaining in the retort, after the distillation was finished, were accurately taken, and are expressed in the following table.

Weight of *Newcastle* pit-coal distilled - - - 96 ounces

Weights of the products.	Liquid -	12	ounces.
	Residuum -	56	
	Loss of weight	28	
		96	

Professor *Newmann* analysed, by distillation, the best sort of the pit-coal found at *Halle*, in *Germany*. He used only 48 ounces in his analysis, but I have expressed the result of his operation, upon the supposition of his having used twice as much, or 96 ounces *.

Weight

* Newmann's Chem. by Lewis, p. 245.

Weight of the *Halle* pit-coal diſtilled - - 96 ounces

Weights of the products.	Liquid -	12	ounces.
	Reſiduum -	83¾	
	Loſs of weight	0¼	
		96	

Dr. *Venel*, of Montpellier, analyſed, by diſtillation, 64 ounces of the pit-coal of *Alais* in *Languedoc*; ſuppoſing that inſtead of 64 he had uſed 96 ounces, the reſult of his analyſis would have been expreſſed by the following numbers*:

Weight

* Inſtructions ſur l'Uſage de la Houille. A Avignon, 1775, p. 45.

Weight of *Alais* pit-coal distilled - - - 96 ounces

Weights of the products.	Liquid -	10½ +	ounces.
	Residuum -	84	
	Loss of weight	1½ —	
		96	

M. *Sage*, of the Academy of Sciences at Paris, says that he has distilled various specimens of pit-coal, taken from different places, and that they generally yielded 2 ounces of liquid from 16 ounces of coal *, that is 12 ounces from 96; which is the same proportion as in the analysis of the Newcastle and Halle pit-coal. He does not mention the weights of the residuums, so that the

* Elémens de Minéralogie. A Paris, 1778, tome prem. p. 94.

the losses of weight, in his distillations, cannot be ascertained.

These several analyses correspond so nearly, with respect to the quantity of liquid procurable from different sorts of coal, that they very much confirm one another; and make it probable, that we shall not be far from the truth in generally asserting, that pit-coal contains one-eighth part of its weight of liquid.

With respect to the nature of the liquid, it may be observed, that when poured out of the receiver, it is seen to consist of three different substances: (1) The middle part is an acid watery fluid, of a reddish colour, it seems as if it was loaded with oil, and it smells of volatile alkali: (2) On the surface of this watery fluid there floats a small por-

 tion

tion of oil, more or leſs liquid and tranſparent, according as the heat uſed in conducting the diſtillation has been leſs or greater: (3) At the bottom there is found a black thick tenacious oil, very much reſembling tar. The two oils together amounted in the diſtillation of the Newcaſtle coal to four ounces, or one-third of the weight of the whole liquid; in the analyſis of the Halle and Alais coals, as well as in the experiments of M. Sage, the two different ſorts of oils were obſervable, but they bore a greater proportion to the whole of the liquid, than in the Newcaſtle coal, amounting to one half of the weight of the liquid. This difference makes me ſuſpect that I committed ſome error, in eſtimating the quantity of oil obtained from

from the diſtillation of Newcaſtle coal. It is probable, however, that the quantity of oil ſeparable from the ſame kind of coal, may be influenced, in ſome degree, by the manner of performing the operation; and there is, moreover, ſome reaſon to believe, that in different kinds of coal the quantities of oil may be very various; as we obſerve them to differ from each other both in their proneneſs to catch fire, and in their ability to ſupport it: though it muſt be owned, that both theſe effects may as conſiſtently be explained, from the difference of the manner in which the oil may be combined with the other principles of the coal, as from the difference of its quantity.

The correſpondence, with reſpect to the quantity of liquid obtained by the ſeveral diſtillations of Engliſh, German and French pit-coal, would induce one to ſuppoſe that the experiments had been reſpectively made with great accuracy; but the great diſparity, as to the quantity of the reſidues remaining after the extraction of the liquid, ſeems to indicate the contrary; for it is greater, I apprehend, than can be accounted for from the different natures of the coals. The German and French analyſes corroborate each other, and the reader may thence reaſonably be diſpoſed to queſtion the truth of mine. He will permit me, however, to produce a teſtimony in its ſupport, and which is, perhaps, the more to

be

be depended on, as I was not aware of it when the analyſis was made.

Dr. Hales *, by diſtilling 158 grains of Newcaſtle coal, obtained 51 grains of *air*. From 96 ounces he would, according to the ſame proportion, have obtained 30 ounces of air; now the difference between 28 ounces of ſome ſort of matter or other which was loſt during my diſtillation of 96 ounces of coal, and 30 ounces of air, which might have been obtained from the ſame quantity of coal by Dr. Hales' method, is ſo ſmall, that it may eaſily be accounted for from the different modes of operating, or from a ſlight difference in the qualities of the coals. Many naturaliſts have thought that pit-coal has been pro-

* Vegetab. Stat.

produced from vegetables, and efpecially from forefts of refinous woods, which have been buried in the bowels of the earth; without entering into all the reafons on which this opinion is founded, I will lay before the reader an account of the products obtainable from different woods by diftillation.

The woods which I diftilled were heart of *Oak*, *Box*, *Mahogany*, and *Sallow*. They were all dry and old, and were cut into fmall pieces, about half an inch fquare, before they were put into the earthen retort. The annexed table fhews, at one view, the refult of the refpective diftillations.

	Heart of Oak.	Box.	Mah.	Sall.
Weight distilled,	96 oz.	96	96	96
Liquid - -	37¼	61½	33½	48
Residuum - -	30	26½	27½	20½
Loss of weight -	28¾	8	35	27½
	96	96	96	96

The liquids separable from woods by distillation, consist partly of oil, but principally of water impregnated with an acid, from which also a volatile alkali may be disengaged. The oil varies in quantity according to the nature of the wood, the hardest woods, and the hardest parts of the same wood abounding most in oil; thus both oak and box contained, in the same weight of the wood, more oil than sallow did. That part of the oil which is first separated from the wood is so light as to float

upon water, and of a yellowiſh colour; its quantity, however, is but ſmall, compared with that of the thick, black, heavy oil, which follows it. It appears from this account, that the quality of the liquid ſeparable from wood by diſtillation, is wholly the ſame with that of the liquid ſeparable from pit-coal by the ſame means.

The matter which is loſt during the diſtillation of both wood and pit-coal has been called *air*, and it certainly has one, at leaſt, of the moſt diſtinguiſhing properties of *air* —*permanent elaſticity*, for bladders may be inflated with it as with common air. It does not begin to be ſeparated from either wood or coal till the lighter of the two oils begins to appear; it then ruſhes out with

great

great violence, and unleſs a proper vent be given to it, the ſtrongeſt veſſels will be burſt by it.

In diſtilling heart of oak, during the courſe of chemical lectures which I read in the univerſity at Cambridge, in the year 1767, I remarked to the audience, that the air which iſſued with great violence from the oak was inflammable, not only at its firſt exit from the diſtilling veſſel, but after it had been made to paſs through two high bended glaſs tubes, and three large veſſels of water. I at firſt ſuppoſed the inflammability to proceed from ſome oily particles which had accompanied the air, and which I thought would ſoon be condenſed by the cold, though they had not been

been condenſed in paſſing through the water; but upon repeating the experiment, and collecting the air in bladders, I found that it retained its inflammability a long time, and burned like the air, ſeparable from ſome metals by ſolution in acids.

From the reſearches which have been lately made on this ſubject, it is now believed, that this kind of air may be ſeparated from all vegetable, animal, and inflammable mineral ſubſtances by diſtillation; and the common burning of wood, coal, paper, pitch, oil, and other combuſtible bodies, is attributed to this air, which being ſeparated from the body by the heat, and inflamed by the contact of the fire, continues to burn as long as the body continues

to afford a proper supply of it. *Inflammable air*, confidered in this view, bears a great refemblance to what the chemifts have hitherto underftood by their *phlogifton*, or food of fire.

Diftillation is not the only means of feparating *inflammable air* from vegetable and animal fubftances, it is found to be produced by *putrefaction.* Stagnant waters, whofe bottoms are covered with putrefying vegetables, yield an inflammable air; the *Thames* water, in becoming putrid, yields an inflammable air: and the fame obfervation may, probably, be true of other river waters which are fubject to putrefaction. An inflammable air has been obferved alfo in fwampy grounds, in cellars, and in privies. There are many inftances recorded,

corded, of a vapour issuing from the stomachs of dead persons, which took fire on the approach of a candle * ; the matter producing that vapour could not, probably, become putrid enough in the stomach, to generate an inflammable vapour, whilst the persons were alive; for Van Helmont has remarked, that the air discharged from the stomach by eructation, is not inflammable, but that it becomes so in the lower intestines †.

From

* Collect. Acad. Tom. III. Part Etrang. p. 16.

† Ructus sive flatus originalis in *stomacho*, prout et flatus ilei extinguant flammam candelæ. *Stercoreus* autem flatus, qui in ultimis formatur intestinis, atque per anum erumpit, transmissus, per flammam candelæ transvolando accenditur, ac flammam diversicolorem, iridis instar exprimit. Van Helmont, Oper. p. 405.

From heart of oak moderately dried, Dr. Hales got one-third of the weight of the oak of the air here ſpoken of; this proportion ſufficiently agrees with the quantity which was loſt during the forementioned diſtillation of oak.

A cubic foot of dry *box-wood* weighs, according to Mr. Cotes' table of ſpecific gravities, 1030 ounces; hence, ſuppoſing that 96 ounces of ſuch wood had only given 61 ounces of liquid, it may appear by an eaſy calculation, that a cubic foot of dry box-wood contains above 5 gallons of liquid; ſuppoſing the liquid to be no heavier than water; and if we admit the oil and the acid, when concentered, to amount to two quarts, the other 18 quarts may be looked upon as pure water; nay, the quan-

tity

tity of water may be conſidered as amounting to almoſt the whole of the liquid, ſince both acids and oils principally conſiſt of water.

A cubic foot of *ſallow* weighs, according to Muſchenbroek, 585 ounces, and ſuppoſing that 96 ounces of ſuch wood would yield by diſtillation 48 ounces of liquid, then a cubic foot would contain about 9 quarts of liquid, which is not half ſo much as an equal bulk of box-wood contains.

I put the matter in theſe different lights, in order to excite thoſe who have leiſure to make ſimilar inquiries, for it is undoubtedly a very wonderful thing, that ſuch large quantities of *water*, and *air*, ſhould be combined with the *earth* of wood, by ſuch a peculiar bond of union as

to

to remain for ages without losing any of their distinguishing properties. And here I am sensible is great room for many physical investigations.—Are the densest woods the most abundant in air and water? Is the air *generated* by the process of distillation, or only *disengaged* from the wood, into the composition of which it had entered, together with water, by *vegetation?* Have the *inflammable airs*, separable from different woods by distillation, the same specific gravity and the same degree of inflammability? Or is the inflammability influenced by the nature of the *oil* contained in the wood? How long will a given quantity of air retain its inflammability? Does it lose it in consequence of the *precipitation of some oily particles*, which are dissolved

ſolved in it, when it is firſt diſtilled? As no particle of matter can be annihilated, what becomes of the inflammable air after it has been inflamed? Is it reduced to an unelaſtic *earth*, or does it ſtill exiſt under the form of an uninflammable elaſtic *fluid?* Whence is it that no air begins to be diſtilled, till the moſt volatile part of the oil begins to be ſeparated from the wood? *Fraxinella* is a very odorous plant; when in full bloſſom, the air which ſurrounds it in a ſtill night, may be inflamed by the approach of a lighted candle: Does this inflammability proceed from an inflammable air, which is exhaled by the plant, or from ſome of the finer particles of the *oil* of the plant, being *diſſolved* in the common air of the atmoſphere? Whence is it that the oils diſtilled

from

from wood, during the ſame operation, are of different colours, conſiſtencies, and ſpecific gravities? Does this variety depend upon the loſs of the air, or upon the quantity of the acid mixed with the oils? Are the oils and acids of different woods diſtinguiſhable from one another, by any ſpecific differences, or do they only differ from one another as to more or leſs? Suppoſing the acids obtained from different woods to be of the ſame ſort, and to be purified to the greateſt degree, what kind of ſalts would they form, when united with alkalies, earths, and metallic ſubſtances? In what manner are the relative proportions of the water, acid, oils, air and reſiduum ſeparable from wood by diſtillation, influenced

 by

by the operation being conducted with a quick or a ſlow fire?

Theſe, and a great many ſimilar queſtions, might be reſolved with the greateſt accuracy, and our knowledge be thereby much advanced. But it falls to the lot of few to be able to build commodious Elaboratories, to purchaſe ſuitable inſtruments, to ſupply proper materials, and to maintain operators to execute the infinite variety of experiments which might be deviſed, for the regular and ſyſtematic improvement of every branch of Chemiſtry.

The reſidue remaining in the retort, after the diſtillation of the wood, is a perfect charcoal, and that which remains after the diſtillation of pitcoal, is a light ſpungy maſs, in appearance,

pearance, and, indeed, in quality, resembling a substance prepared from pit-coal, as an article of trade, and which is usually called *coak* or *cinder*.

At *Newcastle* 24 barrows of coals produced generally but 18 barrows of cinders, and the price of a bushel, or of any other measure of cinders, is commonly one third more than the price of the same measure of coals *. At *Cambridge*, on the contrary, where great quantities of cinders are prepared for the drying of malt in the town and neighbouring villages, the price of cinders and of coals is the same. From this circumstance it might probably be inferred, that the coal was increased in bulk by being converted into cinder, otherwise the merchant would have no compensa-

* Voy. Metal. par M. Jars, p. 211.

tion for the expence attending the procefs. Upon examining the fact, I found that in one inftance 30 bufhels of coal gave 39 bufhels of cinders, and in another 28 bufhels of coal gave 36 bufhels of cinders. The quantity of cinders, being eftimated by *meafure*, depends much upon the cinders being in rounder lumps than the coals; and the real quantity, eftimated by *weight*, depends greatly upon the degree of heat to which the cinder has been expofed. I take the difference in the bulks of the Newcaftle and Cambridge cinder, procurable from an equal quantity of coals, to proceed from the different degrees of heat to which they are expofed; the Cambridge coak ovens being drawn once in 24 hours, and thofe

thoſe at Newcaſtle only once in 48 hours, or thereabouts.

In order to ſee what effect a longer continuation of fire would have upon the ordinary Cambridge cinder, I took a large piece, and having broken it, threw one part of it into the middle of a fierce cinder fire, employed in the drying of malt. This part became red hot in leſs than ten minutes; after it had continued in that ſituation for above two hours, I took it out, and when it was cold I found it conſiderably waſted in bulk, but it appeared to be harder and blacker than the other part of the ſame piece, and its parts were certainly more condenſed; for I found that a cubic foot of the ordinary cinder weighed 1090 ounces, and a cubic foot of that which had been expoſed

to the fire for two hours, weighed 1208 ounces. This cinder was, probably, as much changed in the ſpace of two hours, by the ſtrong draught of the fire in which it was put, as it would have been by a much longer continuance in the coak oven, where the draught of air is very little: and from this experiment it may be inferred, that the quantity of cinders procurable from a definite quantity of coals, depends very much upon the ſtrength and continuance of the fire, ſince the cinder, after it is fully formed, is not only waſted in part by a longer continuance in the oven, but the part which remains is rendered more denſe, and upon both accounts the quantity, eſtimated by meaſure, is leſſened. This obſervation may be of uſe to thoſe who are employed in pre-

preparing cinder for ſale; and upon inquiry I find, that the quantity of cinder procured from the ſame quantity of coal is very variable: when the operation has been longer, or the heat greater than uſual, inſtead of gaining of ſix or eight buſhels from every thirty buſhels of coal, they ſometimes are not able to get even 30 buſhels of cinder.

The conſumption of charcoal in fluxing iron from its ores, and in manufacturing it into bar iron, is ſo very conſiderable, and the price of charcoal, from the great ſcarcity of under-wood in this kingdom, is ſo great, that many attempts have been made to ſubſtitute in this buſineſs charred pit-coal in the room of charcoal. Theſe attempts have in part ſucceeded, and iron is now very

generally extracted from its ore by fires made with coak. But the iron thus procured is very fragile and coarse, and cannot, without great difficulty, be rendered as malleable as that which is fluxed with charcoal; it may answer nearly as well for casting, but it cannot be made into good bar iron by any art hitherto known. Hence it became an object worthy the contemplation of the society for the encouragement of arts, manufactures, and commerce, to propose premiums for the making of pig iron, and converting pig iron into bar iron with coak. The pigs and bars were required to be as good as those made with charcoal; but the premiums, though proposed from 1762 to 1766, were never claimed *.

Those

* Memoirs of Agriculture, Vol. I. p. 220.

Thoſe who are intereſted in iron works, have motives, more prevalent than the ſociety's premiums, to induce them to perfect the art of ſmelting by means of charred pit-coal; and it may not be an uſeleſs hint to them, to try the effect of coak, which has undergone different degrees of heat. I ordered a ton of coals to be put into a coak oven, and when it was in the uſual way converted into a cinder, I found that it weighed 11 hundred weight; had it ſtayed longer in the oven it would have been reduced further, and it may deſerve to be inquired, whether there is not a definite weight to which any given quantity of coals ought to be reduced, in order to produce the beſt poſſible coak for the fluxing of

iron one. The * *Alais* pit-coal is said to lose half of its weight by being reduced to coak, whilst another sort of coal lost only 35 parts in an hundred: this diversity may depend partly on the nature of the coal, but principally, I conceive, on the degree and continuance of the fire used in the preparation of the coak.

"What shall I say further of coals, except I tell you of one *Becher*, in King Charles the Second's time, who pretended to make *pitch* and *tar* from them, but I think his project came to nothing †." This is *Houghton*'s observation concerning a project of one of the greatest chemists that ever lived. Whatever fate his project met with in his own

age,

* Instruc. sur l'Usage de la Houille, p. 81.
† Houghton's Collec. Vol. II. No. 242.

age, it has been realized in ours; for a kind of tar has for several years last past been prepared from coal in the bishopric of *Liege*, and in other parts of Germany; we also make considerable quantities in England, especially near *Broseley*, and at *Bristol* *; a person at Bristol having obtained a patent for making tar from pit-coal, the condition of which, if I am rightly informed, is, that every person who undertakes to procure

tar

* In the Philos. Trans. No. 228, year 1697, there is mention made of pitch and tar being then separated at *Broseley*, in *Shropshire*, from the black bituminous stone which lies over the coal. It was separated, partly by boiling the stone, and partly by distilling it—The present method of obtaining pitch from pit-coal is a great improvement upon the former practice.

tar from pit-coal muſt pay a ſhilling a barrel to the patentee.

The method of making *tar* is thus deſcribed by Newmann.—" Tar is prepared in different parts of Germany, Norway, Sweden, &c. from the pine and the fir-trees, and in ſome places from the larch and the terebinth. The wood is incloſed in a large oven to the quantity of ten or more loads at a time: this ſtands within another oven called the mantle, the ſpace between them receiving the fire. From the bottom of the inner oven runs a gutter, by which the tar is conveyed in proportion as it melts out of the wood*." This proceſs is a kind of diſtillation, in which the inner oven repre-

* Newmann's Chem. p. 288.

reprefents the body of the retort, and the gutter its neck. The fluid parts of refinous woods are probably capable of being melted out of them with a lefs degree of heat than what is requifite for the diftillation of coal, yet the procefs of procuring tar, here mentioned, might be applied, with a few alterations, to the obtaining the thick oil of coals.—There would in this plan be no lofs of fuel, the coal contained in the inner oven would be converted into one of the moft valuable kinds of coak, and the fire between the ovens would afford a cinder as good as the common cinder.

In the bifhopric of *Liege* the coal is diftilled in a kind of ftill compofed of two large caft-iron pots. In England the coal is put into ovens which

which are heated by fires lighted under their bottoms, and the liquid matter is forced through an iron pipe inserted into the top of the oven, and which communicates with proper condensing vessels. As the pitchy oil is very heavy, the distillation, I think, would be most advantageously performed by making the fire on the top of the oven containing the coal; so that the liquid matter might be made to descend through a pipe inserted into the bottom of the oven, and communicating with proper receivers.

In the great works they obtain the very same substances which we got from the analysis of coal—a corrosive watery liquor, and two sorts of oil. The two oils are put into an iron still, in order to their

 being

being further purified from the watery liquor with which they are mixed; 6 barrels of this oily matter produce about 5 barrels of oil of a thicker confiftence; of the oil thus thickened one part is lighter than the other, the lighter part is drawn off from the other, and is not at prefent applied to any ufe; the thicker part is ufed as *tar*, for the paying the fides and bottoms of fhips, but it is not found to anfwer fo well as tar, either for cordage, or to mix with oakum.

Thofe who are interefted in the preparation of coak would do well to remember, that every 96 ounces of coal would furnifh 4 ounces at the leaft of oil, probably 6 ounces might be obtained; but if we put the

the product ſo low as 5 ounces from 100, and ſuppoſe a coak oven to woork ff only 100 tons of coal in a year, there would be a ſaving of 5 tons of oil, which would yield above 4 tons of tar: the requiſite alteration in the ſtructure of the coak ovens, ſo as to make them a kind of diſtilling veſſels, might be made at a very trifling expence.

It has been before obſerved, that wood and pit-coal wholly reſemble each other in the products which they yield by diſtillation, and as the oil from pit-coal is found to anſwer the purpoſe of tar, it might ſurely be a matter worthy the conſideration of thoſe who are engaged in the burning of wood into *charcoal*, to contrive means which might eaſily be

be done, of ſaving all the oil, which is ſeparated from the wood during that operation.

The acid liquor which is procured from pit-coal, when it is diſtilled for tar, is at preſent thrown away, as I have been informed by a perſon who is much engaged in this buſineſs. Without entering into the diſpute concerning the origin of the vegetable fixed alkali, we may obſerve, that it is generally obtained from the combuſtion of the vegetable, and there is reaſon to think, that the *acid* of the vegetable contributes in ſome way or other towards its production; thus the concrete acid of tartar yields, by being burned, a great quantity of fixed alkali. Is it wholly improbable, that the *acid* liquor which is ſeparated from the coal by diſtillation,

 might

might be converted into a *fixed alkali* by being boiled down and calcined, either by itſelf, or in conjunction with ſtraw, charcoal duſt, or any other ſubſtance, containing the inflammable principle?

The making of fixed alkali in Great Britain, is a matter of ſuch great national concern, that the commercial reader will excuſe me, if I give another hint or two upon the ſubject. Might not pot-aſh be prepared in the cyder countries, from the calcination of the *acid* earthy pulp, which remains after the juice is preſſed out from the apple? The brewery *grains* are at preſent applied to ſome uſe; would they not, if ſuffered to turn *ſour*, yield more profit by being calcined for pot-aſh? The brewery hops, which are impregnated with

with the ſweet wort, would probably turn ſour, and as they are thrown away as uſeleſs, might it not be adviſable to ſee whether they would not yield pot-aſh by calcination? The lees and refuſe from the making of vinegar, might be tried for the ſame purpoſe; and ſo might all the water which is impregnated with the waſhings of the floors, veſſels, &c. in which any vegetable liquor is fermented, either into ale or vinegar. I remember having evaporated, ſeveral years ago, a large quantity of horſe's urine, with a view of ſeeing whether it would yield by cryſtallization, the ſame kind of *phoſphoric* ſalt, which may be obtained from human urine; I could not procure any ſalt of that kind from it; but when it was evaporated to dryneſs,

it yielded, even without *calcination*, a great deal of *fixed alkali* The urine of animals, which feed upon vegetables, arises from the juices of the vegetables, which have been changed in some degree by the organs of digestion; may not a similar change take place by putrefaction? and may not the putrefaction of vegetable juices be increased, by a small admixture of common salt? and would not the quantity of alkali be thereby increased? Is it not possible to *decompose* common salt, by mixing it with vegetables in a state of putrefaction? If the acid of salt could by any cheap means be separated from its alkaline basis, it would undoubtedly be the interest of government to exempt from the salt duty, all such rock or sea salt, as should be con-

verted into a fixed alkali; for by that means, all the money might be kept in the kingdom, which is now sent out of it, for the purchase of barilla, and other sorts of fixed alkali.

It has, with some men, been a subject of apprehension, lest all the coal-pits in England should soon become exhausted. The quantity of coal which is annually raised, is certainly very great; and as coal is not found to grow again, the time must come, when it will all be consumed. That æra, however, is certainly at a great distance, since in those counties where coal is found, they are constantly opening fresh pits, and may for centuries to come continue to open more; and coal may, probably, be discovered in many counties, where none is extracted at pre-

ſent. It will enable the reader to form ſome notion of the great excavations, which are annually made in this iſland from the digging of coal, if we calculate the extent of that which is made in one year, in conſequence of the coal which is imported into London. The following account may be relied on:

An account of coals imported into the port of London, in ten years, ending at Chriſtmas, 1779.

Chriſtmas	1770	- -	615,330 chalders.
	1771	- -	694,003
	1772	- -	725,008
	1773	- -	624,781
	1774	- -	623,727
	1775	- -	672,786
	1776	- -	700,207
	1777	- -	697,435
	1778	- -	647,361
	1779	- -	587,895
Annual average			658,853

No

No accounts are kept at the Cuſtom Houſe, diſtinguiſhing the importation from Newcaſtle, Sunderland, Blythe, Hartlepool, &c. or from the ſeveral parts in Scotland and Wales, the Crown revenue not being affected thereby. The duty is 8s. per chalder of 36 Wincheſter buſhels, on all coals ſold by meaſure, and 6s. 4d. per ton, on ſuch as are ſold by weight. It appears from the preceding account, that in the year 1777, there were imported into the port of London 697,435 chalders, and we learn from another authority *, that in the ſame year there were imported from *Newcaſtle* and *Sunderland* alone 692,093¾ chalders; by comparing theſe numbers, we may obſerve how ſmall a portion of the

* Ann. Reg. 1777, Ch. 161

the coal consumed in London, is brought from any other quarter.

A chalder of coals, Newcastle measure, is allowed by Act of Parliament * to weigh 53 hundred weight: and as 8 Newcastle chalders are equal to 15 London chalders, reckoning 36 Winchester bushels to the London chalder, it follows, that a chalder of coals, London measure, is equal to a little more than 28 hundred weight. But supposing 28 hundred weight to be the weight of a London chalder, then as the medium quantity of coal annually imported into London is 658,853 chalders, it may be collected, that there are annually imported 922,394 tons.

The following table expresses the relative

* 6 & 7 W. & M. III. c. 10. f. 2.

relative weights of a few different sorts of coals.

Weight of a cubic foot of

Welsh coal - - -	1396	ounces av.
Yorkshire stone-coal	1307	——
Lancash. cannel-coal	1273	——
Newcastle upon Tyne	1271	——
* Staffordshire coal	1241	——
† Coal de Graissesac	1371	——
† Coal des Carmaux	1333	——
† Coal d'Alais - -	1500	——
Medium weight	1336	ounces avoir.

The Welsh coal was of that kind which burns without giving any smoke, they mix it here with cinder for the drying of malt. The Yorkshire stone-coal was taken from a pit near

* Philos. Trans. No. 169.

† The weights of the three French coals were calculated from experiments mentioned in Instruct. sur l'Usage de Houille, p. 2.

near Wakefield, and is part of the ſtratum, which lies at the bottom of the black coal. The cannel-coal was from Wigan in Lancaſhire: this coal is commonly uſed by the country people to work by in winter nights, inſtead of candles, and its name has been probably derived from its uſe, candles being called in the dialect of the northern counties, cannels.

The Newcaſtle coal was of a kind which is much eſteemed at Cambridge, and which is called *Old Ducks*. The medium weight of a cubic foot of theſe ſeveral coals being 1336 avoirdupois ounces, a cubic yard or 27 cubic feet of coal, will weigh 2254½ avoirdupois pounds; there are 2240 ſuch pounds in a ton, hence we may ſay in general, that a cubic yard

of

of pit-coal weighs a ton; ſome ſorts of coal weigh a few pounds more, and other, a few pounds leſs than a ton. From what has been before obſerved concerning the quantity of coal annually imported into London, we may now conclude that 922,394 cubic yards of coal are annually dug out of the earth for the ſupply of the London market. This quantity of coal, if ſpread to the thickneſs of an inch, would cover an area of above 10 ſquare miles; and no doubt the conſumption of ſo large a quantity contributes very much both to the daily dirtineſs of the ſtreets of London, and to that elevation of ſoil which is ſufficiently obvious in the city and its environs, when diſtant periods of time are compared together.

The

The weight of a London chalder of coals is here put equal to 28 hundred weight, upon the ſuppoſition of 8 Newcaſtle chalders being equal to 15 London chalders. Upon weighing a buſhel of the middle ſized, large, and ſmall *old ducks*, at Cambridge, I found the weights to be

Middle ſized	-	74
Large coal	- -	76
Small coal	- - -	80
Medium	- -	$76\frac{2}{3}$

This medium does not give quite 25 hundred weight to a chalder. I found, by weighing coals at another warehouſe in Cambridge, that 30 buſhels made a ton, which is $74\frac{2}{3}$ pounds to a buſhel.

It is not certainly known how long coal has been dug in Great Britain;

Britain; the first sort of fuel which all nations used was probably wood, and as that grew scarce men began to search into the bowels of the earth for something to supply its place. We have good reason to believe that the Newcastle coal-pits were wrought in the time of the Romans, for coal cinders have been found at the bottom of the foundation of a city built by the Romans in that county*; but whether they were not wrought by the Britons before the Roman invasion, is a question which cannot, perhaps, be positively decided either way.

Anderson, in his History of Commerce, fixes the introduction of Newcastle coal into London at so early a period as the year 1305; and mentions

* Wallis's Hist. of Northumberland.

mentions a complaint of the nobility and gentry, which was preferred to the King againſt the uſe of ſea-coal, as a public nuiſance. A ſimilar prejudice prevails at this day, amongſt thoſe who have not been accuſtomed to pit-coal fires. The great Hoffman had given it as his opinion, that the peripneumony, the dry aſthma, and the conſumption, were common maladies amongſt the inhabitants of Liege and London, and that they were occaſioned by the great uſe of pit-coal in thoſe places. M. Morand, in 1769, was at the trouble to inquire into this matter; and it appears from the atteſtations of the College of Phyſicians in *London*; of the Faculty of Medicine at *Paris*; of the phyſicians at *Liege*, at *Lyons*, and other places,

that the opinion concerning the peculiar insalubrity of pit coal fires is utterly without foundation.

It has been remarked that coal, in being distilled, yields near $\frac{1}{3}$ of its weight of air; in being consumed by burning, it yields a great deal more; for both the residue remaining in the retort, and the oil obtained by distillation, yield much air during combustion. I do not think that it would be an extravagant supposition, if we should say, that the 922,394 tons of coal which are annually consumed, dispersed into the atmosphere incumbent over London, 500000 tons of air; and this quantity may, probably, be about $\frac{1}{4}$ of the whole quantity of air, which is respired by the inhabitants of London in the course of a year.

Hence,

Hence, though it ſhould be granted that the air from coal is not more unwholeſome than that which is ſeparated from any other kind of fuel, yet the vaſt quantity of it with which the common air over great cities is daily infected, may contribute ſomething to the rendering them, what they have been juſtly called, the graves of mankind.

END OF VOL. II.